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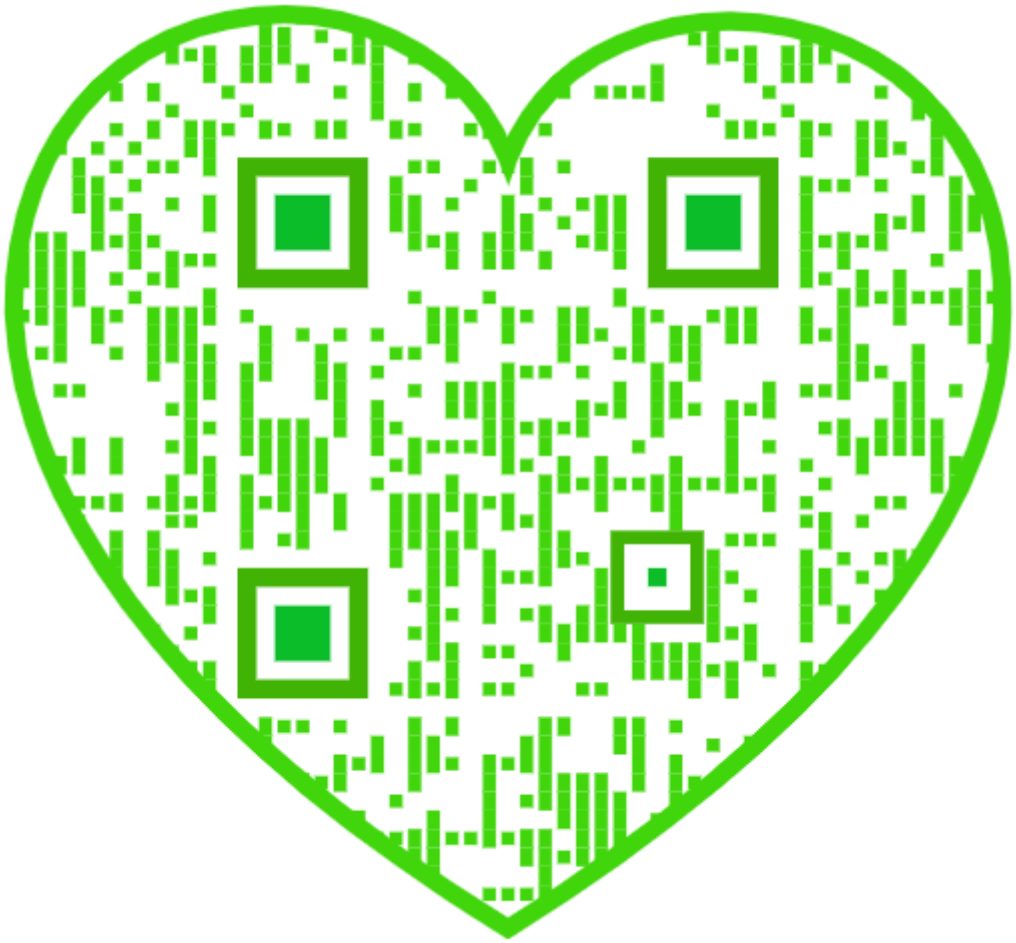

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NAVIGATION

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UNIV. OF

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NAVIGATION

CHAPTER I

Introductory

There is a story, handed down from generation to generation of seamen, which may well serve to indicate the purpose of this little volume. A new First Lord of the Admiralty (let us say, of Barataria) was paying his first official or other visit to a man-of-war. He was received with due ceremony, and escorted to the hatchway leading down to the captain's quarters. There, viewing the uncomfortable ladder and the unknown depths below, he ejaculated (in Baratarian): "Jehoshaphat! *the durned thing's hollow!*"

This particularly unveracious yarn embodies a truth. Ships are, to most landsmen, a new and unfamiliar country; seamen are a peculiar people full of strange language and unexpected customs. And even those who voyage as passengers more or less frequently do not often see much of the working of the ship, and both officers and men are too busily engaged to spare time for explaining technicalities. In particular, it is a mystery to all but the seaman how, from the moment of losing touch with the land, a ship is piloted out of harbour, set fair on her course towards her destination, and located day by day on the chart until she reaches port again.

The aim of this book, then, is to initiate the reader, as far as may be, as a sort of honorary member in the great company of seafarers. Something of the language and idiom may easily be learned; something of the methods whereby huge steel structures are planned and built so as to be not indeed invulnerable but certainly as safe as a railway train; something of

the nature of the craft and skill and knowledge in virtue of which a navigator is able to find his way; something of the machines and instruments that he uses. Such knowledge may help the casual voyager to feel less "at sea" when he is actually afloat. He will understand how it is that every buoy in a harbour indicates a plain message of direction or warning; how the lighthouse, standing wave-swept where land and ocean meet, flashes its name in clear weather or calls it aloud in fog; how the seaman gropes to safety in the dark, touching and feeling the bottom with the lead; and how sun and stars in their predetermined courses are made servants of the mind of man, who deduces his actual position on the ocean from their apparent places in the sky.

But as for pure seamanship, that is to say, the actual practice of pilotage in sight of land and astronomical navigation on the high seas, and the handling and safe conduct of the ship in fair or foul weather, no book can pretend to teach it. Nor is there any road to learning it except through long and laborious apprenticeship to some past master of the craft; and it is thus that the "art and mystery" has been handed down through immemorial time. Moreover, a certain natural jealousy always exists between members of any guild and those not of the brotherhood. Our great city companies were formed primarily to guard the secrets and protect the interests of their craftsmen; and seamen are, in a sense, a company or guild, a confraternity of the sea more sympathetic with foreign sailors than with landsmen of their own blood. Even modern civilisation has not entirely destroyed this isolation or removed the prejudice; and those whose profession lies afloat are apt to seem taciturn and uncommunicative about their work.

One of the first books published to deal with nautical matters was *The Seaman's Secrets*, written by John Davis, the Arctic pioneer, in 1594. The title goes far to justify the remarks just made, and it is but fair to say that Davis expounds the secrets, not of proper seamanship, but only of mathematical navigation.

Another treatise, this time by a gentleman adventurer, Sir Henry Manwayring (1644), states somewhat querulously:

"And as for the professed Seamen, they either want ability and dexterity to express themselves or (as they generally do) will to instruct any Gentleman."

This is an interesting sidelight on the conduct of those expeditions of the Elizabethan age; when ships, manned by Devon sea-dogs, and officered by professed seamen who knew much of the Spanish main and little of the Court, were placed under the nominal command of "soldier gentlemen." One pictures easily how the master mariner would be jealous of his trade secrets, how the other would feel himself helpless through lack of knowledge. Yet we know how loyally both sailor and soldier worked together under the Flag, and how in common danger and privation they learned each the other's craft, laying the foundations of our empire beyond the seas. The present writer claims at least "the goodwill to instruct any Gentleman" who may care to learn something of matters nearly concerning every member of a nation whose prosperity and very existence are founded on sea power.

First, then, it will be convenient to watch a ship in the course of building, to see the nature of the floating structure and the various precautions to ensure its safety, and to learn the names of the various parts. Next, some account will be given of the superstructure and fittings so far as they are common to all ships. The actual propelling machinery cannot be described in so short a space as that now available. After this preface the subject proper, *Navigation*, will be discussed.

Navigation, as a technical term, is the science and art and craft of finding where a ship is at any moment and directing her safely to her destination. Navigation is a *science*, for a navigator must know and understand many things, systematising his knowledge and reasoning instinctively and accurately. It is an *art*, in Ruskin's sense of "that which adorns a serviceable thing," for a ship may be handled clumsily or artistically with equal safety but not with equal satisfaction. It is a *craft*, for it demands that fine co-ordination of hand and eye and brain which distinguishes the craftsman from the hewer of wood and drawer of water.

There are two essential subdivisions. *Pilotage* is the safe conduct of a ship in sight of land or in touch with bottom; *Astronomical Navigation* (technically "*Sights*") fixes the ship by observations of heavenly bodies. To understand the first one must study *Charts* and *Plans*, and learn to read the closely printed information which they present about buoys and

soundings, lights and leading marks; *Sailing Directions*, the "Baedeker's Guide" of the fairways and resting-places of the sea; and *Tide Tables*, which are the "Bradshaw" of the goings and comings of the tide wave. Some description must be given of machines and instruments: *lead*, *log*, and *compass*. For the second, the elementary principles of Astronomy as linked with *latitude* and *longitude* must be considered at some length; also the use of *sextant* and *chronometer* must be explained. There is really no difficulty in understanding *how* a ship is piloted and navigated; but to be a navigator one needs to be a seaman, just as in some degree every seaman is a navigator.

CHAPTER II

The Building of the Ship

Ships resemble one another and differ from one another much as do human beings. Perhaps it would be more correct to say "animals" rather than "human beings," for a coal-lighter and a torpedo-boat have in common about as much as a tortoise and a hare. So in the description of a ship in the building it must be understood that no special ship is under consideration. The object is to show what provisions for strength and what precautions for safety are possible, and on what plan the designer works, without attempting to give weights or measures, which would be out of place here.

A ship consists, then, of backbone, ribs, and skin, like any animal. She has internal supports and partitions, with appropriate functions and machinery, again like any animal. She has a nervous system of communication between her mechanism and her brain, the brain being the officer in charge on the bridge. She needs food in the shape of fuel, and proper rest for repair, and due care in her maintenance. Individual ships differ in their outward appearance and external fittings, but in their essentials of construction they are alike.

All modern ships are built of steel, which is iron containing a certain percentage of carbon. The nature of the steel varies

widely for a very small change in the carbon percentage, and may be still further altered by the addition of small amounts of substances such as nickel, vanadium, and aluminium. But the ordinary material in use is *mild steel*, with one-fifth per cent. of carbon, about. This can be forged and cast and rolled like iron, and possesses the important quality of homogeneity ; it has no *grain*, and is equally strong in all directions. Wrought iron is somewhat scarce nowadays, but the best anchor cables are still made of it. *High-tension steel* contains more carbon and is much stronger. It is specified for work where lightness (with strength) is all important, as in destroyers, whose skin is only some $\frac{1}{8}$ inch thick. *Cast steel* is used for large masses of metal. All metal worked into a ship has to pass severe tests, carried out officially to satisfy the requirements of the Board of Trade and of Lloyd's surveyors, otherwise the ship cannot be "classed at Lloyd's" for insurance purposes. These tests ensure the quality of the metal under pulling and crushing and twisting and bending. All these are *stresses* to which parts of the ship are subject, being *strained* when they yield to the stress. The designer has to calculate the thickness of any part so as to make sure that the strain under the maximum ordinary stress is well within safe limits.

The problem that faces a shipbuilder is to use as little metal as he can, so that the vessel will not only float but also carry passengers and cargo; to make her strong enough to resist rolling and buffeting and vibration, and to be safe even when the hull is pierced in a limited area. There is no such thing as an unsinkable ship. One could be built by filling every hollow space in her hull with cork, but then she would be not a ship but a raft.

The system adopted is that of subdivision into compartments or *cellular* construction. A bamboo stick exemplifies what this means. It is built of innumerable hollow cells in detail, and is divided into water-tight compartments lengthways by the knots.

A practical experiment will explain, better than many words, how even so thin a substance as paper can be disposed so as to resist bending. Take a single sheet of ordinary note-paper, and fold it lengthways into five equal strips. Overlap the outside strips and a square tube results. It is very fairly strong

against bending *so long as it is kept square.* Technically, it is a *box-girder.* Now prepare two or three squares of paper about $\frac{1}{4}$ inch larger, each way, than the section of the tube. Fold their edges up at right angles, making little dishes which will fit the tube, and insert them inside it. Now the tube cannot get out of shape and is much stronger. Finally, gum everything in place, and the structure is most rigid although it is only skin thick. Technically, what has been made is a *box-girder stiffened with transverse bulkheads.* Each bulkhead is formed as one *dished plate.*

The model as made would be liable to wear along the edges or to *buckle* there — that is, to crease up. Take four strips of paper $\frac{1}{2}$ inch broad, folded down the middle, and glue them along the edges. The girder is now strengthened with *angles.*

This kindergarten work has introduced illustrations of nearly all the principles of strength of materials as expounded in scientific treatises, and need not be despised as puerile.

The fingers trying to bend the model testify that it is much *stronger* than would be expected from the material. As to *buoyancy,* it will be found to support about one-eighth of its bulk of iron. As to *safety,* slit up one of its compartments, supposing that there are three of them, and it will not sink.

A ship is built of *plates, beams,* and *angle-bars.* These are joined by rivets. Plates are of any thickness from $\frac{3}{32}$ of an inch up to 2 inches or more for special purposes. They are rolled in pieces up to 4 feet by 30 feet. They are cut by *shears* into any outline, and are bent by *rolls* into any shape within reason. *Beams* are called by the letters of the alphabet which they resemble in sectional shape. They are made up to 90 feet long. A *tee-bar* is T, one of the most usual for spanning the ship from side to side under a deck. The bottom of the down stroke is generally much enlarged, and the bar is then called a *tee-bulb.* An *angle-bar,* or *ell-bar,* is L; miles of it are used for joining plates at right angles to one another, as in the edge strips of our model. A *zed-bar* is Z; it is most convenient where two separate parallel faces are wanted for riveting, as the top and bottom flanges are both clear. A *channel-bar* is [, and an *aitch-bar,* or *double-channel,* is H. All of these have their special uses, but details need not be given. It must be understood, in the sequel, that when plates or parts are said to

be joined, a suitable angle or other bar is fitted, and both are riveted to it.

The process of building may now be described. Along the whole length of the building-slip are massive *keel-blocks*, wooden pedestals on which the middle line of the ship will rest. On either side are railways carrying travelling-*cranes* to pick up material and hand it in. These rails may be on the top of *gantries*, scaffolding extending right along on both sides. Lying handy are piles of timber *shores* for supporting the work as it grows; and all the necessary material is ready prepared, cut to size, bent, and punched with holes where required. We press into service a djinn from the brass bottle of the *Arabian Nights*, to execute the work as fast as it is described.

The backbone of the ship is her *keel*. This is laid as a double thickness of plates with overlapping joints, right along the blocks—the *outer keel*. The *vertical keel* stands upright along the middle line. The *inner keel* is above this, parallel to the lower. All these are secured together by angles so as to form a continuous I girder.

The cranes hand down the head and the tail pieces. These are heavy castings or forgings. At the forward (*for'ard*) end or *bows* is the *stem*, and the appearance of the ship depends in large measure on the shape of it. At the *after* end is the *stern-post*. In a single-screw ship this is a *stern frame* with an opening in which the propeller will revolve. There are fittings to take the rudder.

The two huge pieces are lowered into position and propped there, and are joined up to the keel which is shaped upwards into them. There are *rabbits* or recesses in the castings to receive the ends of the plates which form the skin later on.

Next, the ribs begin to grow out of the backbone. At every yard or so *transverse frames* are fitted. The word *frame* needs some explanation. The strongest is a water-tight frame consisting of a plate with a continuous angle-bar round its edges and possibly a couple of angles across it, slantwise, to stiffen it. If not meant to be water-tight, big holes are punched to save weight, of size enough for a man to creep through. Or, again, where solidity is not required, the frame may be simply of angles built up without a plate. The more

the water-tight frames built in, the safer is the ship. But every ton of metal used means a loss of a ton of cargo.

During this description the djinn has been busy, and there lies on the slip the skeleton of some great lizard. The frames project perhaps 6 feet in the middle, and taper off and round up at the ends. In height they fit the keel amidships.

Next, the *first longitudinals* are worked round the ends of the first frames and into the stern and stern-posts. They are like the keel, but lighter. Then the *skin* begins to cover the bones. The skin plates are riveted to the frames and to one another, and the joints are made water-tight by *caulking*. In this process a chisel is used to make a V-shaped groove along the edge of one plate about $\frac{1}{8}$ inch from the joint. The thin side of the V is thus forced against the other plate, water-tight. The two plates of the outer skin next the keel on either side are called the *garboard strakes*, the middle plate of the inner skin is the *gutter strake*.

The whole structure is now a *double-bottom* consisting of a mass of cells, each one bounded by the outer and inner skins, two transverse frames and two longitudinal girders. Where the frames are water-tight the cell is a *water-tight compartment*. The space is not entirely wasted, for these compartments are available for water ballast and oil fuel and fresh water. Then even if one is pierced no great harm is done; the compartment is already partly full, and not much buoyancy is lost.

The double bottom does not necessarily extend the whole length of the ship; the extreme ends are generally separate compartments shut off vertically instead of horizontally. The actual number of compartments is a compromise between expediency and economy.

Meantime the work has gone on, and more transverse frames have been fitted, another pair of longitudinals, and more skin plates, until the *floor* of the ship is complete, being the inner skin over the *bilge*. The word "bilge" is akin to "belly," and is not quite definite. That is to say, the bilge ends more or less where the sides of the ship turn upwards. Here there is a change in the construction.

The transverse frames taper away into *bracket frames* at the corner and into Z-bars vertically up the sides. Provision

is now made for decks by working T-bulbs right across the ship. These are secured to the Z-bars by *knees* or *bracket-plates*, terms which explain themselves. At the level of each deck other beams are fitted between the vertical Z-bars horizontally from stem to stern, and the deck-plate nearest the side is riveted to these. Where needed this joint is strengthened by an additional plate of high-tensile steel which is called a *stringer-plate*. At the upper deck where the sides end a special skin plate is worked round the whole ship. This is the *sheer strake*. It is generally of high-tension steel, and is firmly secured by angles to the adjoining stringer of the upper deck.

The actual arrangement of decks and holds depends upon circumstances. The vertical partitions are called *bulkheads*, transverse or longitudinal. The ideal of construction is to carry every water-tight frame of the double bottom up to the upper deck as a *water-tight transverse bulkhead*. It is essential to have one of these, called the *collision bulkhead*, near the bows. In case of collision the bows simply crumple up, but if this foremost bulkhead holds firm the damage stops there. It is no uncommon occurrence for a destroyer to suffer in this way and to return safely to dockyard with her nose absolutely out of joint. In all battleships great pains are taken to make the transverse bulkheads absolutely reliable. They are stiffened by heavy channel bars of [section, vertically, and no doors or openings are allowed. To get from one compartment to another the upper deck must be reached.

Again, the ideal is to work a longitudinal bulkhead down the middle line. This is quite convenient when the engines are in duplicate, and gives enormous rigidity to the framework. But it has this disadvantage, that if one side be injured the inrush of water will give the ship a dangerous *list*, heeling her over to that side. Arrangements are therefore made to flood other compartments on the opposite side until she balances again on an even keel.

Further, if the space and weight can be spared, another water-tight longitudinal can be built on each side to form a *double skin* in continuation of the double bottom. This space can be used for coal storage, forming *wing-bunkers* as in men-of-war.

In ordinary cargo steamers it simply would not pay, commercially, to have all this minute subdivision. The holds have to be clear from deck to bottom and from side to side, so that cargo may be stowed and unstowed with speed and economy. In the passenger trade it is unfortunately the case that so much is demanded, in the way of the luxuries of a first-class hotel and club, that the naval architect who wishes to earn dividends for his company must place considerations of reserve of safety after those of advertisement.

In battleships it is probable that the maximum of expense and of efficiency has been touched, with the accompaniment of maximum discomfort to those who have to live in them.

The matter—like most others in life—is one of well-considered compromise. The reader will have been able to form some idea of the principles involved, and will have seen that in all essentials our paper model was built on the proper lines. When all has been said and done, a disaster like that of the *Titanic*, still fresh in memory, warns humanity to remember that nothing heavier than water will float, and that a compartment opened to the sea reduces that part of the ship to mere gravitating metal. Build a ship how you will, and then rip her along one-third of her length on one side, and she cannot float for long.

It is interesting to consider the ways in which a ship strains under stress of sea and weather. She *pants* when the skin works in and out under the changing water pressure, especially at the bows. Extra angles are worked there to stiffen the plates against the impact of the waves as she meets them.

She *racks* during rolling, as when the paper tube tended to get out of the square. This strain is resisted by the transverse bulkheads and by the knees and bracket-plates where the deck beams join the sides. She *sags* when she bends downwards in the middle of her length. Here a little hydrostatics must be introduced in explanation.

Archimedes, settling himself gently into his brimful bath until he floated with nose and chin above water, grasped two main ideas which were new to science. He reasoned: (1) My body is supported by something, that something is this water, and as I can be supported only by a force equal to my weight, the water pressure on my body is equal to my weight.

(2) The only difference in things before and after I got in here is that I have substituted my body, barring nose and chin, for the water that was there before. *Ergo*—The total weight of my body exactly equals the weight of the water displaced by the immersed part of my body when floating—*Eureka!*

Apply this to a ship. The actual weight in tons of the whole fabric and contents above and below water is equal to the weight in tons of the water which would fill the hole made in the sea by her hull up to the water-line. This weight is her *displacement tonnage.* Now imagine her cut up into lengths down the middle of each water-tight bulkhead. If each compartment floated at the same water-line, each would be said to be *water-borne*, and if the flat ends were now riveted together again there would be no tendency for the ship to bend at the joints. But considering how the weights of engines, cargo, stem, and stern are actually distributed, it is clear that some sections are too heavy for their displacement, and tend to sink; others are too light, and tend to rise. Where such sections join, the ship tends to bend one way or the other. A floating man keeps his head above water by using the muscles of his neck to hold it up, and generally forces his toes out of water by this effort.

Even were the weights so placed that each section was water-borne in *still* water, as soon as waves were encountered that part of the hull over the *hollow* would tend to sag, that over the crest would tend to *hog*—"*hogging*" being the opposite of sagging.

The whole disposition of the ship is admirably adapted to resist bending. For to bend, either the top must lengthen and the bottom shorten, or *vice versa;* and the various stringers, including the garboard strakes and sheer strakes, are fitted to take the strain. Yet a ship does bend visibly. In the superstructure of battleships, near the mid-length, is found an *expansion joint* where the two parts can slide over one another. In a sea-way, as the ship alternately sags and hogs, this joint opens and shuts. The writer has seen it open wide enough to admit a lead pencil.

Economy is a relative term, and has no meaning where the value of human lives is concerned. But the skilled naval architect who can design and calculate so as to obtain the same

efficiency, for less cost in material, labour, and time, practises true economy and serves his nation well.

Our djinn has completed his labours, fitting the ship with machinery and superstructure and fittings. These will form material for another chapter; but they cannot be described in detail, as they range from the palatial accommodation of a transatlantic liner to the scant furniture of a tramp. But in all essentials the two vessels are as alike as the human bodies: one of the millionaire in his royal suite of staterooms, and the other of the stoker earning his day's wage down below.

A ship has to *find herself*. It is a general principle of all structures that they are most sound when, under any stress, the strain is distributed as widely as may be. There is a classical instance in O. W. Holmes' "One Horse Shay," so craftily built that no part could break or wear out before any other. In the end, logically, it went suddenly (not to pieces, but) to dust. The ship on her trials groans and *complains* aloud as she suffers from various and complicated stresses. Rivets ease infinitesimally, joints give a hair's-breadth, and every part adjusts itself microscopically till it takes a fair share of the work. So, many members duly compacted in one body, she takes up her appointed duties for pleasure, for profit, and for peril.

Not without fair reason does the seaman still attribute sex to his ship. No two ships behave alike, even when built from the same designs. Nor does any one ship do the same thing twice in exactly the same fashion. She is as capricious as a woman in fair weather, and as patient in foul. And her master, the boatswain, must tend her and humour her and guard her, according to the ancient wisdom that wondered equally at the way of a ship in the waters and the way of a man with a maid.

CHAPTER III

Learning the Ropes

In old sailing days a youngster joining a new ship was allowed forty-eight hours, by the custom of the sea, to "sling his hammock" and to learn the ropes. We remember how Marryat's

Mr. Easy took longer to find his sea-legs and to recover from seasickness, and it takes much more than two days for an officer to get to know his craft. For a modern ship is a mass of complicated machinery which demands some knowledge of engineering and science to supplement pure seamanship. Moreover, no two ships are fitted alike. Therefore it is only the essentials that can here be mentioned as we go on board.

Approaching, flags are noticed. At the stern is the *ensign* staff, and the nature of the ship may be known from the ensign that she *wears*. There are three ensigns, red, white, and blue in their ground colour, originating in the old navy when a fleet went into action in three divisions, each division flying its own colour and being commanded by an Admiral of the Red or White or Blue. To-day the Great Union or Union Jack occupies the top quarter next the staff. The white ensign bears also the St. George's cross (vertical and horizontal white stripes). This flag denotes that the vessel is a man-of-war under the King's commission. It is not only a gross breach of etiquette, but a punishable offence for any other to wear it. There is but one exception: the Royal Yacht Squadron has the Sovereign's charter to hoist the white ensign so long as it is clear that she is not afloat for warlike purposes. The Blue Ensign has no cross; it is appropriated to vessels on public service or to merchant ships under the command of officers who hold a King's commission in the reserve. Thus it is worn by many liners, as well as by diplomatic officials, Board of Trade and other departments, each carrying some distinguishing device. The Red Ensign has no cross. It denotes nationality pure and simple, and is worn by all ships sailing "under the Flag." It should be remembered that no one ashore has any right to hoist any ensign; the only flags allowable are the plain St. George's cross (*argent*, a cross *gules*) for churches and hospitals, and the Union Jack for all citizens engaged on the King's business.

The Union Jack is worn on the jack-staff in the bows of every man-of-war, and over fortresses or naval establishments ashore. It takes its name from Jacques (James I), who authorised the union of the national flags of St. George, St. Andrew, and St. Patrick. The first has been described—a red cross on a white ground. The second is a white diagonal cross

on a blue ground (*azure*, a saltire argent); the last, a red diagonal cross on a white ground (*argent*, a saltire *gules*). For heraldic reasons, which would take too long to explain, the white ground of the St. Patrick's red cross *is not symmetrical*. Its broader white edge is uppermost next the staff when properly worn. To turn the Great Union upside down is a signal of extreme distress or of extreme ignorance. All sailors and soldiers who have served with the colours, whatever their rank, are entitled to wear the Union Jack on their last journey to the grave; and a seaman carried feet-foremost over the side to his burial receives the same honours of the bos'n's "pipe" as an admiral leaving the ship.

By the custom of the sea all ships salute the white ensign by dipping their own, the salute being returned. In the past, when Britain was more punctilious about her prestige, many a pretty sea-fight arose from the non-observance of this custom. Some of the older generation of seamen commanding sailing ships follow another very old tradition, by dipping the topmost sails which they may be carrying. This is very rarely seen. A still rarer occurrence is to see a ship's rigging *scandalised*—that is, all the yards set askew and awry. This is a mark of mourning for royalty; the writer has seen it done on Good Friday in Latin waters by pious Roman Catholics.

It is impossible to give any account of other flags and ensigns in the space available. But it is perhaps of use to mention that flags half-masted mean death; a *yellow* flag is quarantine; a yellow with black quarters is plague; *blue* with a white centre-square is the *Blue Peter*, signifying a ship about to sail; the *black* flag is worn only in romances of pirates and after an execution on board; the *red* flag of Socialism is not known afloat, but a *red burgee* (a flag with a V-piece cut out) denotes danger from explosion above or below water.

The character and status of a British ship may thus be known long before we board her. An old sailor would also be able to tell her line or owner from her funnel markings; would guess at her time out from harbour by her height out of water, showing how much she was short of coal; would appreciate signs (almost invisible except to Dr. Sherlock Holmes) informing him what the cargo might be, and whether she was clean or dirty, with a smart or a lazy crew.

The ship is entered, either over a *gangway* on to the upper deck, or through a *port* in the side leading to the main or lower deck. There may be a cargo deck below these. Everything above the upper deck is *superstructure*. It may involve promenade decks, sun decks, and other places for passengers, with a boat and spar deck above all. But all steam vessels have, as an essential, a navigating *bridge* from side to side of the ship, forward of all superstructure. The bridge is sacred to officers and men on duty. It contains the eyes and brain of the ship as an entity. The engine rooms are connected with it by telegraphs, and (without detraction from the intellect and skill of engineers who care for the motive power) the bridge directs the life and motion of the ship. This place and its fittings will have full description later.

The idiom of the language changes as soon as we are afloat. Towards the ship's head is forward (*for'ard*), the opposite direction is *aft*. The right hand looking for'ard is *starboard*, the left is *port* (not *larboard*, which is obsolete). The quarter from which the wind blows is to *windward*, and its opposite is to *leeward* (pronounced *loo-ard*.) The centre line of the ship is *amidships*, the extreme outside edges of a deck are *scuppers*. Thus one might hear of a seasick friend as lying in the lee-scupper on the fore side of the after-gangway. If one were right for'ard on the windward or weather side, it would be necessary to walk aft and cross over to leeward to rescue him.

The length of the ship was divided into four quarters. The foremost and aftermost quarters were occupied by the forecastle (*fo'csle*) and after-castle in days when the military complement lived in and fought from them. Any picture of the Armada shows these veritable fortified castles. The name fo'csle survives, meaning any covered-in place in the bows on the curve of the ship's lines. The word after-castle is obsolete; that part of the ship is the quarter-deck, and the curved lines aft are the ship's *quarters*. But old sailors marking gear as belonging to various parts of the ship still write "AX" and "FX" for the after and fore castles. In liners the after end is the steerage, and in some modern battleships where the crew live aft it is the after-deck, so there cannot be said to be real uniformity. If the after-deck is covered it becomes a *poop*

and poop deck. The middle half of the length is the *waist*, regardless of the fact that it is the thickest part of the body!

All these names have come down from sailing days, although the advent of steam has altered circumstances. The sailing master conned his ship from a raised poop, and that deck was reserved for officers' privacy, being the bridge of a modern ship. It should be remarked that technically a ship has three masts—fore, main, and mizzen. The fo'csle was for'ard of the fore-mast, the quarter-deck abaft the main-mast, the poop abaft the mizzen. In the Royal Navy even at the present time the "hands" are "told off" for duty as fo'csle-men, foretop-men, maintop-men, and quarter-deck-men—the four quarters or parts of the ship, each under its own captain or petty-officer. The captain of the foretop was originally in actual charge of the working of his sails, from the "top" where the foretop-mast joined the fore-mast—a matter of good seamanship and great responsibility. His title survives, although his duties as a sailor have vanished. A *midshipman* obviously had his duties amidships as a subordinate officer concerned chiefly in seeing that superior orders were carried out. The name now implies a young officer, ranking with senior officers socially, but junior to warrant officers (boatswain, gunner, &c.) when on duty.

On the fo'csle are the anchors and anchor gear. There should be two *bower* anchors, one on each bow, and a *sheet* anchor in reserve in case one of the bowers is lost. At the stern is the *stream* anchor, used to prevent the ship swinging as a stream turns. A *kedge* (possibly akin to *catch*) is a small anchor which can be taken away in a boat and dropped, so that the ship may pull or *warp* herself up to it. Ordinary anchors lie on sloping ledges or beds; the cables lead from them round *capstans* and down cable lockers, where they are stowed. The cable leaves the ship at a *hawse-hole*. When getting an anchor in, the cable is *shortened in* till it is up-and-down; the anchor is *aweigh* as soon as it is broken out of the ground. It is then *hove in* till the anchor is close up to the hawse-pipe, and can be taken and hoisted to its bed by a small crane called a *cat-davit*.

Mooring is securing by two anchors. When the two cables get twisted there is a *foul hawse* and much trouble. In this connection it is somewhat curious that the seal of Admiralty

contains a fouled anchor—that is, an anchor with the cable twisted round its shank. To avoid fouling, the two cables are brought together and shackled on to a single *swivel* which, as its name implies, allows the ship to swing round without putting any turns in the cables. Again, to simplify anchor work, *stockless* anchors are much used. Their shank is clear, and is simply hove up into the hawse-pipe, leaving only the arms and flukes outboard.

Besides the anchors, there are other means of securing a ship. *Hawsers* made of stranded steel wire can be led from *bollards* or stout pillars, through *fair leads* at the side, to be made fast to bollards ashore. At wharves and docks these shore bollards may be capstans, rotated by power, for warping a ship alongside.

At intervals along the ship are boat *davits* for getting the boats in and out. These are small cranes which can rotate about their fittings, so that when a boat has been hoisted up she can be turned inboard. Further, for loading and unloading cargo and for getting out the larger boats stowed amidships, there are *derricks* on the masts. A derrick is another kind of crane with a boom or arm reaching out clear of the side, and capable of being raised or lowered.

Into the domestic arrangements of living rooms and cabins (American, *saloons* and *staterooms*) we cannot enter. But it may be noticed that a window is a *scuttle*, a stairway is a *companion* ladder, a passage is a *gangway*, a bed is a *bunk*, and a kitchen range is a *galley*. But a *galley* is also the captain's own boat.

And the actual propelling machinery must be left for treatment by professional engineers; it cannot be adequately treated in short space.

The bridge will now be visited, but only by special favour of the captain when no actual business is in hand. It is a breach of etiquette to intrude there or to draw the attention of an officer on duty away from his work.

Climbing aloft we have a view over everything. The funnels and masts block the view astern, but otherwise the horizon is clear all round for 6 miles or so in every direction, if we are, as is likely, 30 to 40 feet above water. In a large ship there may be a chart-house and (or) a captain's cabin on the

bridge, and it may have shelters at either end and a wheel-house for the man steering, or it may be open except for a canvas breast-screen around it.

The steering *wheel* is amidships, just aft of the steering *compass*. It must be taken for granted for the moment that the compass indicates direction; it will be described in full in its own section. The same remark applies to other instruments. The wheel does not itself move the rudder, it merely opens or closes valves in the steam steering-engines down below in the *tiller* compartment right aft. The gearing is most often mechanical, consisting of long rods connected by toothed wheels, but electrical or hydraulic communication is now fitted with great advantage. The rudder is actuated by a *tiller* or handle running forward from the rudder-head. When the tiller is moved to *port* the rudder goes to *starboard*, so that "giving her port-helm" means turning to starboard, and *vice versa*. This is productive of much confusion at first but it cannot be helped, for the idiom is fixed. One wonders how mistakes were avoided when the word *larboard* was also in use instead of port. The French, with their usual lucidity of expression, use the order "*Tribord!*" (Starboard) as meaning "*turn* to starboard"; while we say "Port" to the helmsman when we wish to turn the other way.

Among the other prominent fittings are the *engine-room telegraphs*, dials with an index which can be set to full or half or slow speed ahead, or astern, or to stop. A similar index and dial on the control platform down below repeats the order there through suitable gearing. Telephones also connect bridge and engine-room.

A *Revolution Indicator* is driven from the main shafting, and the speed is known from the number of revolutions made per minute by the propellers.

The *Sounding Machine* (see section on Soundings) should be on or near to the bridge. With its help the seaman feels his way, touching the bottom with the sounding lead.

There may be, if the ship is modern and her owners generous, two telephones communicating with apparatus on the bows on each side, receivers for hearing the submarine fog-bells now established. There must be some means of sounding a fog-horn or fog-siren or steam-whistle. There must be signal flags

stowed in pigeon-holes ready to hoist to masthead or yards on the signal *halliards*.

In the chart-house are the various charts, instruments, and books used in calculating, either graphically or numerically, the position of the ship.

Here then is the ship's brain. She *sees* with the telescope of the officer on watch and with the eyes of the lookout aloft. She *hears* with the submarine telephone. She *feels* and touches with the lead, and even *tastes* by sampling the nature of the bottom brought up on the lead. Her nervous system of mechanical gearing or electric cable extends down below and aft and for'ard; she speaks with flags or by siren blast; she controls her motive and directive engines. "*Behold also the ships, which, though they be so great, and are driven of fierce winds, yet are they turned about with a very small helm, whithersoever the governor listeth.*"

CHAPTER IV

Proper Pilotage

The title of this chapter does not imply that there is any pilotage which is improper. The phrase is traditional, defining the safe conduct of the ship when in sight of land and in touch with the bottom by soundings. Thus the sections deal with *Charts* as absolutely indispensable, and then in greater detail with *Soundings*, *Lights*, *Buoys and Beacons*, and *Fog Signals*. The chart itself is a synopsis, in shorthand and in symbols, of all information which is necessary for proper pilotage.

CHARTS

A chart is a special map for the use of seamen. It shows the land only so far as it can be seen from afloat, with reference chiefly to prominent objects suitable as marks for guiding a ship. It shows the coast line with indications of its nature, as sand or reefs or cliffs. Finally—and here it differs from a map—it shows the nature and depth of the bottom of the sea,

as well as all dangers to navigation and all helps to navigation —buoys, lighthouses, and light-vessels.

At first sight a chart looks a difficult thing to understand; it is full of symbols and abbreviations, but everything is on a uniform system of shorthand, not hard to learn and easy to remember, since it is based on sheer common sense.

The Admiralty charts are published under the superintendence of His Majesty's Hydrographer, who is a naval officer selected from the surveying service, and thus of necessity skilled both in the science of nautical surveying and in the practical navigation of ships. His duties include the direction of the survey work constantly going on in all parts of the world, the accumulation of material for the making of new charts and the correction of old charts up to date, and the selection and supply of all navigational books and materials to men-of-war. The Hydrographic Department does not advertise, but does more useful work than most Government offices at a minimum of cost to the public. This department has no connection with politics!

The Admiralty charts are fine instances of copperplate engraving; this form of printing is found to lend itself best to the constant corrections which are necessary. The plate can be scraped down and re-engraved. So great is the care exercised in their issue that the agent (Mr. Potter, Minories, London) is not allowed to sell any chart which has not been corrected by hand, in red ink, according to the latest available information. No other charts enjoy so great a reputation for reliability, and all others are necessarily founded on them, since the British surveyors were first in the field. This does not imply the suggestion that the charts of other nations do not possess their special merits, it is a legitimate expression of satisfaction that something made in England cannot be beaten for all-round excellence. It is worth mentioning, in this connection, that when the squadron of the ill-fated Admiral Rodjestvenski was fitted out for its long and last voyage, the ships were supplied with British charts as the best obtainable.

The cartographer is confronted at the outset with the fact that it is impossible to represent any part of the spherical surface of the earth accurately upon a flat piece of paper. This is fairly obvious, but in order to understand the problem

and its approximate solution it must be treated mathematically.

The earth is taken as a sphere, the radius being 3960 statute miles. The polar axis about which the earth rotates is taken as a fixed direction.

If any *plane section* of a sphere be made (as when one cuts clean through an orange with a knife), the shape exposed is circular. Now make plane sections all at right angles to the axis, beginning at the North Pole. The sections increase in size up to that one which passes through the centre, then they

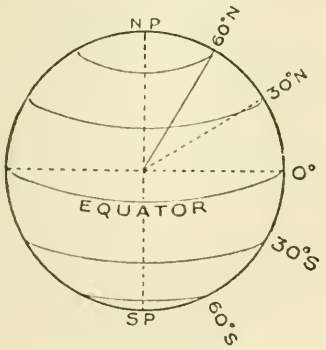


Fig. 1.—Parallels of Latitude.

decrease again. The central section is called a *great circle*, the others are *small circles*.

All the circles of this system are parallel; they are *parallels of latitude*, and the central and largest is the great circle of the *equator*.

The sketch *attempts* to show the system of parallels over a hemisphere; it *succeeds* in showing how hard it is to represent a curved surface on the flat. The parallels are numbered in degrees from 0° at the equator through the 90° each way north and south to the poles. Clearly it does not matter whether the degrees are regarded as *arcs* or distances along the surface or as *angles* at the centre. The meaning of

"I am in 30° N. latitude," or "I am in 60° S. latitude," is plain.

Next, the equator is divided into 360°, measured 180° *east* from Greenwich and 180° *west*. The earth is supposed to be sliced up by sections through the polar axis, one for each degree. These are *great circles*, all at right angles to the equator and to the parallels of latitude, and are called *meridians of longitude*. The sketch again attempts to show them.

It is easy to see that every meridian is equally divided into

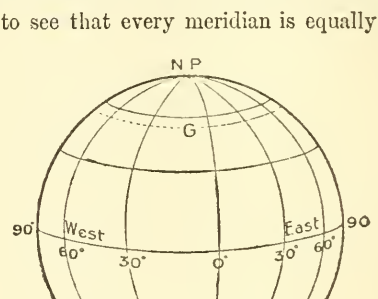


FIG. 2.—Greenwich is placed in position, in 51° 28′ 38″ N. Latitude.

degrees of latitude, and that *all these degrees are of equal length* on the surface. Each degree of latitude contains 60′, minutes; and one minute, 1′, is called a *sea mile*, taken at 6080 feet. Distances at sea are invariably measured in sea miles, and speeds in *knots* of one sea mile per hour. "Knots per hour" is bad English and worse mathematics.

Again, it is seen that every parallel is equally divided into degrees of longitude, but that *these degrees vary in length on the surface* according to the latitude in which they are measured. Longitude is not distance, it is the angular division of a circle. A degree of longitude has the following lengths in sea miles in various latitudes:

Length of 1° of Longitude										
Latitude . .	0°	10°	20°	30°	40°	50°	60°	70°	80°	90°
Sea miles . .	60	59	56	52	46	39	30	20	10	0

These are correct to the nearest mile.

In the latitude of Greenwich, a place distant 60 miles due east from Greenwich would be in longitude 99′ east, or 1° 39′ E.; a place in longitude 60′ east would be distant 37 miles.

At any place, reckoning on the surface, due north and south is the direction of the meridian, and due east and west is the direction of the parallel. Move to another place, and *these directions are no longer the same.* But the navigator directs his ship on her course at some fixed angle from north or south towards east or west, and he must be able to draw his track as a straight line on his chart while he is steering on one course, or the conditions would be intolerable and calculations or *reckoning* impossible.

So it is agreed that in *charts*, as distinguished from *maps*, all the meridians shall be drawn as equidistant parallel straight lines; making the chart-length of 1° of longitude the same all over the chart. Then, if the course of a ship is N. 60° W., he can draw it as such as a straight line.

But this makes everything else all wrong. Longitude is not distance, and if we equalise the 1° of longitude on the chart we must distort the 1° of latitude in proportion, and *the scale of distance and latitude will vary* as latitude varies. This is actually done, and is not as inconvenient as might be supposed. The advantage of having both meridians and parallels drawn as straight lines outweighs all other considerations. The change of scale is shown in the table on next page, the numbers given being the chart-lengths of 1° of latitude above and below the chosen parallels, expressed in terms of the uniform 1′ of longitude.

This shows that if a chart extends from 0° to 60° latitude, the scale of the chart is twice as great at 60° as it is at the equator, so that comparison of *sizes* of countries is impossible.

Length of 1° of Latitude										
Latitude . .	0°	10°	20°	30°	40°	50°	60°	70°	80°	90°
1° below . .	60	61	64	69	78	92	118	171	330	?
1° above . .	60	61	64	70	79	94	122	180	364	?

In fact where under 90° the mark "?" is placed, the size of a square mile on the chart would be infinite. But, first, a seaman is not concerned with sizes; and, second, he does not ordinarily go above 70° latitude; so he is perfectly well satisfied with the chart. Even at latitude 70°, where consecutive degrees of latitude measure 171 and 180 units, the actual distortion is not great. For if 1° of longitude measured 6 inches on the chart—that is, one tenth of an inch to 1′ longitude—a sea mile in latitude 69° would be 0.279 inches long; in 70°, 0.292 inches; in 71°, 0.307 inches: and the difference is about three-hundredth of an inch, which is too small for the eye to appreciate.

In a chart of the English Channel the scale of latitude is to all intents and purposes invariable. In a plan of a port like Plymouth it is constant. But it must be remembered, as the distinction between charts and maps, that a chart has *two* scales—a varying one for latitude and distance, and an invariable one for longitude *which cannot be used for distance.* Distances are measured on that part of the latitude scale which is nearest to them, and are accurate in practice.

Admiralty charts are of four descriptions. *World charts* on a small scale show data such as magnetic variation, coal stations, telegraph cables. *Ocean charts* cover areas such as the North Atlantic on a larger scale, but do not pretend to show details of a coast. They serve for the voyage, but not for the arrival. *General charts* contain very full information over a limited area, *e.g.* the Mediterranean Sea. Finally, *Plans* of harbours, on the largest scale, are a detailed record of the survey up to date. They are generally to scale of 6 inches to a mile, but there is no rule except convenience and the importance of the place. The two sheets printed here are

sketches only, not reproductions, as otherwise the mass of detail would obscure them. It will be a relief to the reader to turn from mathematical discussion to inspection of the sketches.

The first shows the Eddystone Lighthouse with the dangerous patch called Hand Deeps, near it. (Fig 3.) It illustrates very well the use of leading marks to avoid a danger in approaching a port. The leading line is drawn and indexed thus:

Breakwater Light in line with Mt. Batten Tower 37° (*N.* 53° *E. Mag*).

To help in the recognition of the marks, a drawing of the landscape as seen in the proper position is also given in the margin of the chart. Observe the soundings everywhere; they are in fathoms. The 30-fathom line is close to the Eddystone, the 20-fathom line inside is still closer, and on Hand Deeps is found a 4-fathom patch ringed with a 5-fathom line.

Note the scale of longitude at top and bottom, and that of latitude and distance at the sides.

Read the printed information near the Eddystone light. It is not easy, as so much has to be packed into a small space.

Now turn to the second sketch. This is a *plan*, not a chart. (Fig 4.) There are no scales at the margins, but one special scale of one sea mile and cables or tenths at the bottom. It shows the eastern entrance to Plymouth Sound, between the Tinker and the Shagstone. There is a leading line, and a channel buoyed for guidance. Passing the Breakwater Beacon on the left, Duke Rock is right ahead, guarded by a buoy on the 5-fathom line.

The subjects of lights, buoys, soundings, &c., are each treated in some detail in their own sections later on, and these sketches should be referred to when the separate sections are read. Enough has been said at present to indicate the nature of a chart and its indispensability in pilotage. It is true that pilots and natives of a port know their buoys and bearings and marks as by instinct through long experience, but a proper knowledge renders a navigator independent of pilots so long as he has his chart at hand.

Sailing Directions are, briefly, the "Baedeker's Guides" of the

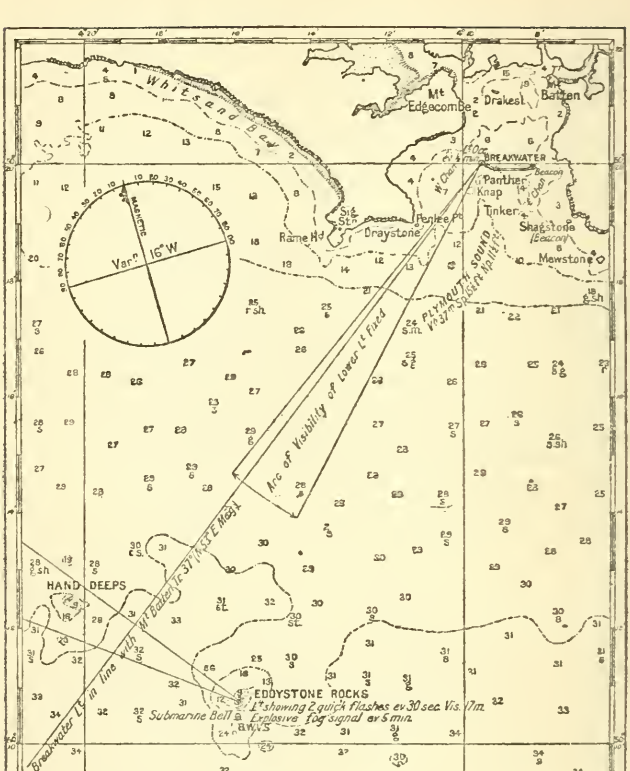


FIG. 3.—Chart of Western Approach and Plymouth Sound.

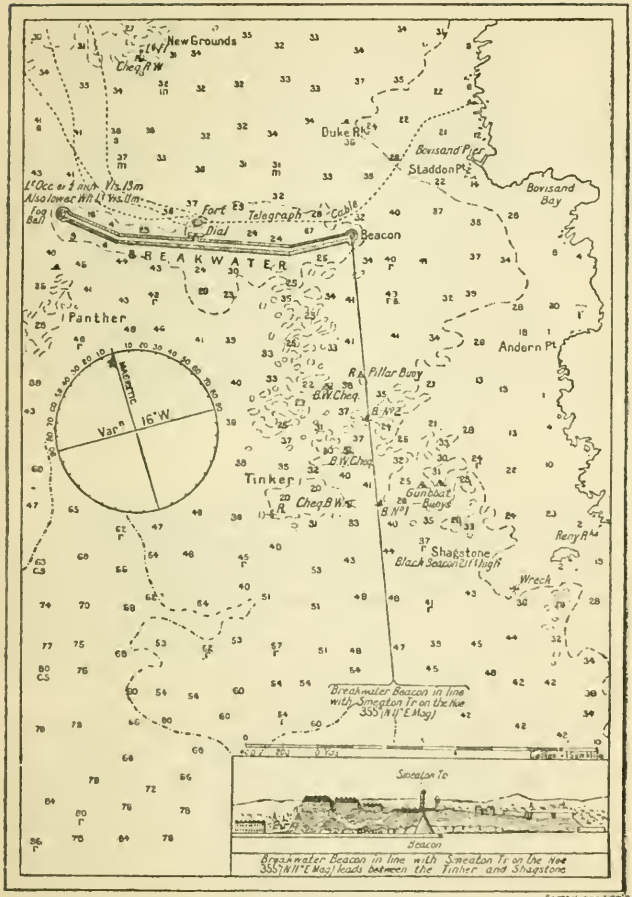


FIG. 4.—Plan of Eastern Entrance and Plymouth Sound.

sea. They describe the winds and currents, the seasonal changes, the facilities for coaling and watering and docking, the lights and beacons and dangers and channels, in great detail. Thus they supplement the charts. But the chart is always corrected up to a later date than the Sailing Directions and is to be preferred in case of difference.

Light Lists give full descriptions of all lights throughout the world, again supplementing the charts. These will be referred to as necessary in the sequel.

The navigator works on the chart with ordinary drawing instruments and on the principles of ordinary geometry. He observes bearings with the compass, and transfers them to the chart; he notes objects when in line, and marks that line on the chart; he measures distances from a lighthouse (say), and scribes the corresponding circle. In many ways he thus secures a *line of position*, and where two lines of position, being simultaneous, intersect, there is the ship fixed on the chart.

SOUNDINGS

A ship is of a certain "*draft*" or "*draught*" (the spelling is immaterial), and needs so many feet of water to float her with something to spare for safety under her bottom. A chart shows the depth of the water found by sounding at any place. The soundings are to be read as meaning the *least* depth of water ever found at the place; technically, they are "reduced to low water of ordinary spring tides," a phrase which will be explained when tides are considered.

Suppose that a battleship draws 30 feet, and that in a channel where she wishes to pass the figures on the chart are 7, 6, 6, 7, 6, 7 (meaning fathoms of 6 feet), then even at *lowest* water there is six feet to spare, and she could certainly enter at high water or near it. But if there were any sea running to cause a swell she would be wise to avoid the passage at or near low water, for the margin of safety is not great when the risks are considered. Yet if the place were well known and constantly used, so that it was certain that no dangers existed, she would be justified in using the channel in case of need, but not for convenience only, even at low tide.

The Sailing Directions are emphatic on the point. They shift the burden of responsibility on to the shoulders of the navigator.

"*Instead of considering a coast to be clear, unless it is known to be foul, the contrary should be assumed.*"

There is no way of measuring depth except by dropping a "*lead*" with a "line" to the bottom, and reading the depth in feet or fathoms, and reducing to low water as explained above. It is thus that each sounding has been obtained by officers and men of the Admiralty Surveying Service, under his Majesty's Hydrographer. There is obviously a limit to the number of soundings that can be made, owing to the labour and time involved. The boats run lines of soundings 100 feet or 100 yards apart according to the nature of the survey No use could be made of closer work, for reasons not immediately obvious but easily explained.

The largest-scale plans of harbours are not often more than six inches to a sea mile, which is almost exactly one-tenth of an inch to 100 feet. Now two figures of ordinary lettering take up a square of one-tenth inch side, so that at the very most not more than one sounding can be printed for a square of the sea surface 100 feet each side. But if figures were printed as closely as this, there would not be room for anything else on the chart. The soundings shown are the actual depths at the place, but they assert nothing at all about what may be the depth between that point and the next. *There is no certainty that dangers do not exist where no dangers are shown.* Blanks on the chart indicate simply that no information is available. If a ship continues long enough in using uncharted routes, she will sooner or later give her name to a shoal or rock which she discovers by the easy method of running on to it. Here comes in the yarn of the Irish pilot taking a ship up harbour. Asked whether he was well acquainted with the place, his answer was: "Shure, I know ivery rock of her, and (*as the ship bumped*), begorra, there's one of 'em."

The only way to make absolutely certain that a channel is clear down to a required depth is to *sweep* it. This is done by two boats, one on either side, steaming abreast and keeping distance. They carry between them at the set depth below water a wire heavily weighted at the ends and buoyed in the

middle, or a steel bar. Any isolated *pinnacle rock* is thus discovered and may be mined and blown up, or a softer bottom can be dredged out to the depth that is necessary.

Dotted in among the lines of soundings are *contour lines* of equal depths, just like those of equal heights on an ordinary map of a hilly district. These lines when drawn are in some degree a guarantee that the survey has been close and is considered reliable. The meaning of the line, in *fathoms* of six feet, is expressed by the way it is drawn. The notation is

Fathoms	*Line*	*Fathoms*	*Line*
one	. . . . .	ten	. — . — . — . — .
two	.. ..	twenty	.. — .. — .. — .. —
&c.		&c.	
five	....	fifty	..... — ..... — ..... —

The 100-fathom line is ....., continuous dots, it can never be confused with the one-fathom line.

On large-scale plans the soundings are in *feet* not in fathoms. Every chart and plan explains, under its title, how the soundings are to be read.

The use of soundings is well illustrated by the familiar story of St. Paul's shipwreck in Acts xxvii.:

"About midnight the shipmen deemed that they drew nigh to some country; and sounded, and found twenty fathoms: and when they had gone a little further, they sounded again, and found it fifteen fathoms. Then fearing lest they should have fallen upon rocks, they cast four anchors out of the stern, and wished for the day."

Under the circumstances the shipmen behaved in a "proper and seamanlike manner"—which is, nautically, high praise. The water was shoaling rapidly, five fathoms less in only a little way, and they had no charts or lighthouses in those days. But approaching Malta and Gozo nowadays, under like conditions of weather and finding the same soundings, the chart would have told them more or less where they were instead of their having only a general fear of rocks. In fact if the course and speed were known, the position could be narrowed down within quite a small area.

The manner of sounding by hand has probably changed very little since that voyage. The leaden weight called the *lead*

weighs ten to fourteen pounds. It is exactly like the balance-weight of an ordinary window, except that there is a cup at the bottom which is filled with tallow. As the lead strikes the bottom this tallow *arming* picks up a specimen of the floor of the sea—sand or shells or pebbles. The nature of the bottom is a valuable guide to position, of course.

The leadsman, standing up in the chains and leaning outboard, swings the lead round his head vertically and heaves it as far forward as he can. Then he gathers in the line quickly, so as to have it taut when the ship comes up over the lead. He reads the depth when the line is vertical. The line is marked in a traditional manner with tags of leather and bunting at irregular intervals of 2, 3, 5, 7, 10, 13, 15, 17, 20 fathoms. If the depth is one of those *marked*, the leadsman calls it in a peculiar sing-song, "*By the mark: five!*" or whatever it may be. If it be not a marked figure, he sings it out as, "*By the deep: nine!*" The numbers five and nine have been chosen to show how the system which seems arbitrary really distinguishes two words easily confused in sound. The pseudonym "Mark Twain" adopted by a notable American humorist was a reminiscence of his days as a Mississippi pilot in shallow-draught river steamers, where two fathoms meant trouble ahead.

Hand sounding must always be laborious, and at ten fathoms it is slow. Yet in men-of-war the pipe, "Leadsmen in the chains," is made whenever the ship is nearing harbour or leaving it. In deeper water, when soundings are taken for information and not as a precaution, *Thomson's Sounding Machine* (Lord Kelvin's) is used. This is one of the most useful instruments of navigation; Lord Kelvin describes its gradual invention in his *Lectures* (see Bibliography, p. 95). The description now given is that of the latest pattern.

The lead is twenty-four pounds weight, the line is seven-stranded very thin steel wire. The wire is coiled on a drum holding 300 fathoms. The drum has an automatic break governing the speed of running out and counting mechanism showing the amount of wire reeled off. An electrical motor may be fitted to haul in the lead to save both time and labour. The machine is set up on or under the bridge, where it is close to the navigating officer's post. A spar is rigged out well

clear of the ship's side, and is stayed by a topping-lift and guys. On this spar runs a carrier with a pulley: it can be hauled out to the end of the spar. The wire is led from the drum through the pulley, then to the lead. When the ship is not moving, soundings are obviously quick and easy.

But the originality of Lord Kelvin's invention was its adaptation to taking soundings without stopping the ship, so as to get an up-and-down cast of the lead. He provided a brass cylinder, closed at one end, and fitted at the other with an air-tight piston. This was slung above the lead, and as it sank with it the pressure of the water forced the piston inwards, compressing the air. An index was fitted, to be pushed along by the piston on the inward stroke, but to remain when the piston recoiled as the lead was hauled in. The position of the index gave the depth, since the volume of a gas is inversely proportional to its pressure. This instrument was not entirely satisfactory owing to leakage and some slip of the index. It was replaced by a narrow glass tube closed at one end. The water itself forms an air-tight piston. The index is made automatic by coating the inside of the tube with red chloride of silver which turns white under the action of sea water. So as the tube sinks the depth is recorded in colour, and is measured by comparison with a scale properly divided.

There still remained the necessity of reeling in the wire and getting the lead and tube on board to read the depth. Experiments were made by the Hydrographic Department, and an empirical law was established, connecting the speed of the ship and the length of wire run out with the vertical depth. This has proved quite reliable, and is in general use. The depth corresponding to any speed and fathoms run out may be read from a special table or from a dial graduated for speeds.

One man can work the sounding-machine when a motor is fitted, and can get a sounding each minute, steaming 10 knots in 20 fathoms. A tube may be used as a check now and then, to guard against the possible effects of current in the length of wire reeled out before bottom is reached.

One more type of sounding-machine may be mentioned—the *Submarine Sentry*. This apparatus can be towed behind the ship *at a set depth* up to 40 fathoms; it is on the principle

of a kite, only that it sinks instead of rising. A *tripper* is provided, which disengages on striking bottom and allows the sentry to rise to the surface, at the same time ringing an electric bell on board. This will probably come into universal use.

The 100-fathom line is generally regarded as the limit of pilotage soundings, in distinction from deep-sea soundings, which are of scientific rather than navigational interest. In thick weather the only possible guide to position when nearing land may be the picking up of the 100-fathom line. In the Royal Navy it is part of the routine.

The *arming of the lead* has been mentioned. There are special symbols on the chart denoting the nature of the bottom at a place. A few of the more common are: *c.* coarse; *cl.* clay; *d.* dark; *g.* gravel; *m.* mud; *r.* rock; *st.* stones; *sh.* shells; *w.* white; *oz.* ooze.

A classical instance of the use of these symbols is in the approach to the Channel. The same soundings of 73 fathoms occur in two places 125 miles apart. These might be mistaken, only that one is marked "*f.s.*" (fine sand) and the other "*oz.*" (ooze).

As a practical example, suppose the ship to be steaming east at 15 knots, that is, a mile in four minutes. A cast is made, and the result is 96 fathoms with broken white shells on the arming. The ship's position on the chart is known within a circle of 30 miles diameter, most probably; and if *near* her supposed position there can be found the indication "*96, brk. w. sh.,*" it is something of a verification of the reckoning. *But no reliance is to be placed on a single cast of the lead.*

Twenty minutes afterwards, sounding again, 75 fathoms, dark mud, is found; and after another twenty minutes, 50 fathoms, gravel. In each interval five miles have been travelled. If now we can find on the chart three places—

(1) near the supposed position,
(2) lying on the course due east,
(3) at the proper interval, five miles,

showing *brk. w. sh.*; *d. m.*; *g.*, then the cumulative circumstantial evidence can be accepted as convincing. Navigation by soundings is not only a precaution but a definite method of

finding position, thanks to the labours of the Surveying Service and the inventive genius of Lord Kelvin.

In the *King's Regulations* and *Admiralty Instructions* the captain, the navigating officer, and the officer of the watch are severally made responsible for the taking of continuous soundings when approaching and when in sight of land, even in the most frequented channels and even should there be a pilot on board.

No excuse, then, need be made for the amount of space which has here been devoted to the subject of soundings. The "shipmau" of St. Paul's ship who, "deeming that he drew nigh to some country, sounded; and, when he had gone a little further, sounded again," is the type of the careful and conscientious navigator in the twentieth century. Only, no longer need anchors be dropped: the chart not only verifies position and warns of danger, but also leads the ship to safety and the haven where she would be.

LIGHTS

The earliest lighthouse of any importance was the beacon fire set in a tower on the little island of Pharos at Alexandria. This ranked as one of the seven wonders of the world, and is said to have been 600 feet in height, but as it was destroyed by earthquake in the thirteenth century no reliable measurements exist. It supplied the generic name of a lighthouse to all the romance languages: in French *phare;* in Italian and Spanish *faro;* in Greek, of course, φάρος. Our own Flamborough Head (*flame*-town) may be compared.

Space does not admit of any account of the gradual evolution of the modern scientifically equipped lighthouse from the open beacon fire on a tower or cliff. Modern development has been along two lines: first, the advance of lighthouses from dry land out into the sea; and, second, the economy and concentration of the light by lenses and mirrors so as to show a *distinctive* signal easily recognisable.

A shore light needs no special building, but where the site is wave-swept the foundations must be carried well down into the solid rock, often below low water; a solid base must be erected reaching above high water; and then the actual tower is raised, shaped according to mathematical law into that figure

which best resists the tremendous impact of wave and storm and tide. Not only have the ingenuity of engineers and the endurance of workmen been sorely taxed in the construction of the massive and shapely towers which now stand keeping watch and ward where land and ocean meet, but the toll of lives has been heavy—a premium of insurance paid for the safety of future seafarers. The design of lighthouses is a special branch of engineering, and the workmanship is of the highest order, the individual stones and the successive courses being mortised and dovetailed one into the other, and further strengthened by metal bonds. The story of lighthouse building would merit a volume to itself. The present Eddystone, for instance, is the fourth, the final result of patient experiment and labour and daring. The Bishop Rock light is one of the finest in existence, and the third of its line. The original was an open-work steel structure, which was swept away by storm just as it neared completion. A stone tower replaced it and stood firm for a time, although the seas experienced on that outlying end of the land were of such range and violence that a quarter-ton fog-bell hung a hundred feet above water was simply removed during a gale. The tower has now been armoured with an outer casing of granite blocks, dovetailed with precision into themselves and the old work. It seems probable that in the future the system of reinforced concrete will be applied to erect lighthouses as practically monoliths of cement on a steel frame.

The intent and purpose of a lighthouse is to provide a *Landfall*—that is, a recognisable mark visible as far as possible seawards to ships approaching land. The useful rays are thus limited to those which sweep the horizon, and means are provided to deflect all the light into one horizontal plane. This is done by mirrors which *reflect* the light—the *katoptric* system (Greek *kata* = against); or by prisms *refracting* it as it passes through them—the *dioptric* system (Greek *dia* = through); or by prisms which both refract and totally reflect eternally—the *katadioptric* system. In this last, where reflection takes place entirely within the body of the prism, there is no loss of light by dispersion, as happens at the face of an ordinary mirror.

Then again where, as is often the case, only a small part of the horizon has to be lit, another system of lenses or a modi-

fication of the first must be fitted to concentrate the rays into one pencil or shaft of light, instead of wasting them in a belt spread in all directions. It would serve no purpose to enter into constructional details which tax the ingenuity of a specialised branch of opticians. It must suffice to say that it is possible to confine nearly the whole of the available light into one limited pencil or two or three pencils. These are of enormous intensity and penetrative power.

The next requisite after distinctness is distinctiveness. The navigator seeing a light must be able to recognise it and shape his course thereafter by that knowledge. An obvious suggestion is to colour the rays, but this involves so great a loss of power that colours are reserved chiefly for small harbour lights, where no great intensity is required. As a matter of fact, if a white light is of power 100 on some arbitrary scale, the introduction of a red screen reduces it to 40 and a green screen to 25. Still, colours are used in some first-class lights for special reasons, and then the prisms are designed so as to augment the red and green sectors and make their penetration equal to that of the white. But total range of visibility must be lost. There is a fine light in Gage Roads, Fremantle (W. Australia). Here the fairway lies between two dangerous regions, and navigation is somewhat perilous. The lighthouse shows a central white sector over the channel for safety, and a red sector on the left and a green sector on the right. If the ship passes into a coloured region she is immediately warned of its danger.

In a lecture on "Lighthouse Characteristics," delivered at the Naval and Marine Exhibition of Glasgow (1881), Lord Kelvin strongly advocated the extension and universal application of a principle already in partial use at the time and now fully developed. Most people have seen the flashing lamps used at the mastheads of warships for signalling purposes. Their long and short flashes in groups of not more than four constitute letters or symbols of the Morse code of telegraphy. The sequence is too rapid for use in lighthouses, but the principle is the same. Each light has its own ordered series of flashes separated by dark intervals, or of continuous rays separated by short eclipses. This may be arranged in many ways by turning a gas jet up and down or by switching an electric light on and off, suitable machinery being controlled by clock-

work as in the illuminated advertisements which are now so common.

But in the best lights the whole apparatus of prisms and lenses and mirrors is made to revolve continuously, so that the entire light is always usefully employed. The weight may be a couple of tons, so special devices are employed to reduce the friction. The most elegant as well as the most efficient is to float the revolving part on mercury. The circular base fits with only small clearance into a circular trough into which mercury is poured until the iron floats. Since mercury weighs 13½ times as much as water, therefore (quite irrespective of the *quantity* of the fluid) a foot depth of mercury in the clearance space will support two feet of metal with practically no friction, and a powerful clock is sufficient to rotate it.

Suppose now that the whole circumference of the lantern is divided into sectors, which when rotated give the following sequence:

light	dark	light	dark	light	dark	light	dark
3 secs.	1 sec.	1 sec.	1 sec.	1 sec.	1 sec.	1 sec.	6 secs.

and then repeats again and again; this would give to any telegraphist the impression of the Morse code "*B*"

— • • • — • • •

called aloud four times a minute. There is probably no such actual light in existence, but there is one at Minot's Head, Boston, U.S.A., which flashes

• • • • • • • • • • • • • • • •

twice a minute, counting the number 143 continuously. The Eddystone gives two flashes in quick succession each thirty seconds, the Start one single flash each twenty seconds. As a general principle any two lights within 100 miles of one another are given quite different characteristics. Thus no one could confuse the two important neighbours just mentioned.

The combinations of light and dark have technical descriptions, by which they are known and recorded on the chart in shorthand. *Fl.* is *flashing*, *Gp. Fl.* is *flashing in groups*. These imply that there is less light than dark, on the whole. In contrast, *Occ.* for *occulting*, and *Gp. Occ.* for *occulting in*

groups, mean more light than dark, the light being periodically occulted or eclipsed. The phrase "flashes of darkness" has been employed quite happily for this type. A steady light is *F.* for *fixed*, a *revolving* light is *Rev.*, an *alternation* of colours without any eclipse is *Alt.* Colours are abbreviated as *W.* white; *R.* red; *Gn.* green.

Thus on the chart near the lighthouse one might find

"Gp. Fl. W. R. ev. ½ m."

and would look out for two quick flashes, white and then red, separated by a longer dark interval and recurring twice a minute. It would be hard to mistake such a light.

But there is always the possibility of fog, the seaman's bugbear. No fog-breaking light has been invented, nor does it seem to be likely. So although the chart indicates near each light its range of visibility, *e.g.* "vis. 21 miles," this is merely conventional. "Range of visibility" means the distance at which it could be picked up on an average clear night by a man standing on a deck 15 feet above water, and cannot be taken as mathematically accurate. Thus the glare of a first-class light like Ushant North-West is often seen far beyond its nominal range; or, on the other hand, the rays may be diffused by haze or blanketed by fog at five miles distance. In fog to look for a light is, according to naval parlance, like a blind nigger hunting a black kitten in a coal-hole. But fog and fog-signals are discussed in a separate section.

An important point in connection with range of visibility is the effect of raising the observer. A liner's bridge may be 90 feet above sea-level, and the horizon obviously increases with the height of the eye. This is a very simple rule which is worth stating; it is quite reasonably accurate.

Take the square root of the height in feet. Increase the result by one-tenth of itself, and you have the distance of the sea horizon in sea miles.

A look-out man 81 feet above water could just see a boat on the horizon 10 miles off ($\sqrt{81}=9$; $9+1=10$) in clear weather and with a good telescope. A ray from a light 100 feet above water would graze the horizon 11 miles away ($\sqrt{100}=10$; $10+1=11$). So the look-out could pick up the light, theoretically, at 21 miles, adding his range and that of the

light. But in this, as in all nautical matters, allowance must be made for weather and circumstances; and the experience which consolidates itself into instinctive and immediate right judgment can be won only in the hard school of life at sea.

BUOYS AND BEACONS

When a sailor says "*bwoy*" instead of "boy," as is usual among educated people, he is asserting a tradition of the sea. For *bwoy* is Hakluyt's spelling, and the French is *bouée*, which has nothing to do with *boue*, mud. A *buoy* is anything that floats and is moored or anchored to indicate a channel or mark a danger. A *beacon* is a mark erected on a base either on land or on (say) a reef, in a fixed position, and by an extension of usage the term is also applied to distinguishing shapes fitted to the top of buoys. A *leading mark* generally implies the use of two objects, *e.g.*—

"*Beacon on east spit in line with white cairn leads clear of shoal.*"

The primitive buoy (and a perfectly good one) would be a long pole, fastened at one end to a big stone by a rope, dropped overboard where a rock had been found. This shape is still used (a *spar* buoy) to mark the end of a spit of rock running out from the shore. The most complicated kind is a gas buoy, weighing some tons, charged with compressed gas to last some three months, possibly also with machinery for whistling or ringing a bell, the necessary power being derived from the energy of the waves.

There is no uniform international system of buoyage, but in British waters certain rules are laid down. Buoys are distinguished by shape and by colour, so that they may be identified when seen, and their meaning is known according to simple and invariable laws. The chart indicates buoys conventionally by sketching the shape, and describes the colouring in shorthand. Thus (always supposing that the buoy has not drifted out of place) its purpose as showing the safe channel or warning of a danger is clearly indicated.

The notation of the chart for colours is *B.* black, *R.* red, *W.* white, *Gn.* green, *Cheq.* chequered; *H.S.* and *V.S.* horizontal and vertical stripes respectively. Thus "*Gn. W.H.S.*" is read as meaning "green, with white horizontal stripes." As regards

shapes, a *conical* buoy has an ogive head (like a lancet window in a church); a *can* buoy is a flat-topped cylinder; a *pillar* buoy has some central erection on a broad flat base; a *spherical* buoy shows a dome above water; a *spar* buoy is simply a mast. Beacons on buoys are of shapes easy to recognise and always of a dark and whole colour. The descriptions *staff-and-globe, staff-and-cage, diamond, triangle,* explain themselves. Each special colour, shape, and mark means something.

The British system lays down that when a ship is approaching a harbour or river entrance from seaward, or proceeding with the main flood of the tide, the safe channel is to be buoyed as follows:

On the starboard, or right-hand side, are buoys, conical, whole-coloured, and with staff-and-globe beacons (if any.)

On the port, or left-hand side, are buoys, can-shaped, different or particoloured, and with staff and cage beacons (if any).

This rule of the fairway is very simple, and ensures the finding of the channel after picking up the outermost buoy. Shape and colour are both distinctive. The colour may vary: in England the starboard-hand conical buoys are generally red, and the port-hand can buoys chequered. In Scotland the colours are invariably red for starboard and black for port. It is most important to remember that the colours of a ship's lights (red for port, green for starboard) have nothing to do with the colours of buoys.

Green is reserved for warnings of artificial or temporary restrictions of navigation. Wrecks are marked by green buoys lettered "WRECK" in white; submarine cables by similar buoys lettered "TELEGRAPH"; mine-fields are outlined with green-and-white chequered buoys.

The spherical shape denotes permanent obstructions. Thus "middle grounds" (isolated shallow patches in a harbour or anchorage) are known by spherical buoys with white horizontal stripes. The outer or seaward buoy carries a diamond beacon, the inner buoy a triangle.

Mooring buoys are big steel cylinders lying horizontally in the water, secured in position by heavy anchors and cables. They are fitted with eyes to which a ship may make fast her hawsers. Anchor buoys are small *nun* buoys (sharp conical shape) dropped with the anchors to mark where they lie. But

any sort of small barrel, coloured green for starboard and red for port, may be used for this purpose. It is very necessary to mark the position of an anchor, not only so as to be able to steam up to it and weigh it up and down, but also to avoid the chance of some other ship dropping her anchor on top of it with infinite possibilities of trouble.

Local port authorities may make their own arrangements for special buoys for special purposes, such as laying out a regatta course or assigning yacht anchorages, so long as they do not contravene the general laws.

It will now be clear that a navigator entering or leaving harbour can pick his channel, avoid a wreck or a rock, round a middle ground, and either moor or anchor in safety, simply by reading his chart and attending to the buoys. He is like a townsman who knows the colours and signs of all the omnibus routes; an uninitiated passenger is in the position of the country cousin, confused and lost, and unable to appreciate signs which he that runs may read.

FOG SIGNALS

Fog is the most capricious of natural phenomena, and to the seaman it is the most detestable. It ranges from a widespread haze of "water-dust," which is translucent if not transparent, to thick localised banks of fog in which one's hand is barely visible. Wind and foul weather and heavy sea are accepted as more or less in the day's work, things to be fought in the open; but with fog there falls over a ship a veritable wet blanket and a sense of depression and helplessness.

The air always contains a certain amount of water vapour—that is, of water in the gaseous and transparent state. The amount of water which the air can take up depends on the temperature, a given temperature corresponding to a degree of *saturation* with water vapour. If the temperature rises, more water can be vaporised. If it falls, part of the gas must condense into water, and hangs in the air for a time as water-dust until larger water-drops are formed, which descend as rain in the ordinary way when the fall of temperature covers the whole field of the air over an area. But under conditions

which are still not fully understood in detail—chiefly irregular distribution of temperature in successive layers of the air—the condensation manifests itself as cloud, rain, mist, haze, or definite fog. This explanation is confessedly inadequate, but is correct so far as it goes. For instance, suppose that off the Banks of Newfoundland a mass of air *relatively* warm blows over a sea surface *relatively* cold, the water vapour condenses and fog results.

But no theory has been formed to account for the vagaries of fog. It may be perfectly opaque on deck or on the bridge, and yet a man at the masthead may have a clear view over a sea of dense fog, from which masts protrude like those of sunken wrecks; or a wet, dank mist may hang about miles of coast, as so often happens when a ship making the entrance to the Channel comes home to a taste of real west-country weather; or the banks may be isolated in thick patches, none of great extent individually, but together covering many square miles; so that a ship runs in and out of the dark like a train on a railway of many tunnels.

Again, sound travels in a most irregular way through fog. It seems to be reflected at the denser patches and to be diffused (so to speak) elsewhere. Indications of the direction and distance of the source of a sound cannot be trusted. Add to this that lights are invisible, and some part of the danger and discomfort of fog may be appreciated.

There are, of course, special clauses in the "Rule of the Road" for the conduct of ships during fog, and these will be considered in another place. At present an account will be given of the fog signals which are worked from lighthouses and light-ships.

The bell of the Abbot of Aberbrothock is the prototype of fog signals, and *bell-buoys* are fairly common. The striking is done by metal balls rolling freely in paths set out radially in a frame surrounding the bell, the bell itself being fixed to the buoy. When there is a swell the buoy rolls, and the balls roll in and out along their paths, striking the bell at the end of their inward course. But in a dead calm, which is favourable for fog, there is no rolling and no sound.

Whistling buoys make use of the fact that a buoy rises and falls relatively to the water. The water pressure thus available

is made to compress air in a reservoir, and this escapes through a large whistle.

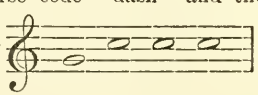
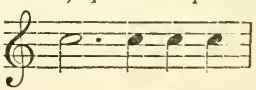
Of a different type is the *explosive fog signal* used in lighthouses and also at some coastguard stations. Guns have always been used on board men-of-war to fire blank charges as warnings or signals in thick weather; but it has been found that a charge of gun-cotton or tonite fired electrically in the open makes an explosion which carries sound further. The charge is slung on the end of the jib of a sort of crane which can be swung out clear of the gallery of the lighthouse, and is detonated by closing an electric circuit from inside. Lighthouse bells have mostly been replaced by explosive signals.

To distinguish the place, the explosions take place at regular intervals, just like the flashes of the light. The Eddystone is marked on the chart "Explosive fog signal every five minutes."

A *Siren* emits a musical note instead of a noise. What we call "sound" is the interpretation placed by the brain on pulses or vibrations in the air received by the mechanism of the ear and transmitted along the nerves electrically to the brain cells. When there are regular or periodic pulses, the effect is a sustained "note," otherwise we "hear a noise." It needs 256 vibrations per second to produce a sound in the middle of the scale of the piano, "tenor C," say. Such vibrations may be determined by the length of a piano wire or a violin string or an organ pipe or a bell. But when quantity and not quality of sound is wanted, the successive impulses are produced by allowing air or steam under high pressure to escape through holes mechanically opened and shut at the proper intervals. This machinery is called a Siren. Conceive a fixed hollow cylinder about the size of a top-hat, closed at the top and connected to a steam pipe at the bottom. Let there be slots cut lengthwise along the cylinder, fitted with slanting vanes like those of a revolving chimney cowl; and place outside it a second cylinder exactly like it, closely fitting but free to revolve. Now turn on the steam. In escaping, it drives the outer cylinder; this, in rotating, alternately covers and uncovers the slots; and, according to the pressure employed, a continuous note of higher or lower pitch is maintained.

This is the principle of the ordinary siren. It has a certain disadvantage, for as the rotating part gets up speed the note rises, in pitch and volume, in a sort of agonised howl. This is most effective in attracting attention; but, besides being a libel on the Sirens of mythology, lacks what musicians call "attack," and is consequently deficient in carrying power. A better plan is therefore to drive the rotor electrically, and admit the air or steam by a governor, which acts only when a set speed is attained. In this way a sharp beginning and end and a definite pitch are secured for the note.

Besides the speaking part, a siren has a trumpet-shaped throat to direct and concentrate the sound towards the sea. This may be 15 or 20 feet long. But nothing can be done to guarantee that the note of the siren shall carry any given distance or in any given direction in the uncertainties of fog. Nevertheless, the signal may be made distinctive so that the place can be recognised. The principle of long and short blasts has been tried, but was found to be liable to mistake owing to echo and the difficulty of knowing when a blast really began and ended. Accordingly, the signals are made not very frequently, with a fair interval between them. Thus the Lizard has *two* blasts a minute, the Start has *one* every two minutes, the Eddystone (between them) has one *explosion* every 5 minutes. This trio of lights are among the most important guarding the Channel entrance, and they are perfectly distinct one from the other in their signals.

Another method is to have two sirens of different note, as it is found that even the unmusical can easily distinguish high from low pitch. The low note corresponds quite naturally to a Morse code "dash" and the high one to a "dot." Thus a call of  gives the impression of the Morse — • • • or *B*, quite independently of the length of the notes; while  might be heard as — • • • *B*, or — • — • *C*, or • • — • *F* owing to interference with the sounds.

It is but recently that experiments with *submarine bells* have resulted in apparatus of practical utility. Water transmits vibrations much more surely and uniformly than in air, and with sharper definition. And the disturbance of the surface of the sea by waves very soon dies out, so that when a wave is 10 feet from crest to hollow, there is calm water at a depth of 20 to 30 feet. A ship must be fitted with *ears* to take full advantage of these under-water bells which are now being established chiefly in light-ships. The ears are placed under-water, one on either side of the ship, towards the bows. They are simply telephones specially adapted to the work, and wires are led from them up on to the bridge. They can receive the sound of the bell, rung at the lightship, up to 10 miles away. The navigator has one telephone receiver at each ear, and can judge of the direction by the relative strength of the sounds. By turning the ship's head until the two sounds are equalised, she may be made to point towards the source. It is probable that this system will be further developed—there are obvious applications in warfare. Among the stations where these bells have been established are the light-vessels at the Shambles (Portland), Royal Sovereign (Beachy Head), East Goodwin Sands, and the Tongue (Thames).

An extract from the *Sailing Directions* (Channel Pilot, Part I.), may serve to conclude this account of danger signals. The *Tongue* light-vessel is described on the chart in two lines of abbreviations, thus—

Tongue Lt., Alt. Gp. Fl. (2) *ev.* 30 *sec. R.W.*
Submarine Fog Bell.

The *Sailing Directions* print full details :—

"**Tongue Light-vessel** (51° 30′ N., 1° 23′ E., Var. 14° 50′ W., Chart 1607), at the eastern entrance to Princes Channel, is painted red with the word *Tongue* on her sides. . . . The vessel exhibits a *group-flashing* light giving one *red* and one *white* flash in quick succession every *half-minute*, thus :—*red* flash *two seconds;* eclipse *six seconds; white* flash *two seconds;* eclipse *twenty seconds.* The light is 40 feet above the sea, and should be seen in clear weather from a distance of 11 miles. . . .

"**Fog Signal.**—In thick or foggy weather a siren gives

three blasts every *two minutes*, thus: high note *two seconds;* silence *two seconds;* low note *two seconds;* silence *two seconds;* high note *two seconds;* silence *one hundred and ten seconds.*

"**Submarine Fog Bell.**—In addition to the fog signal above mentioned, a submarine fog bell has been established on board the *Tongue* light-vessel, which, during thick or foggy weather, will be struck *four* times in quick succession, followed by an interval of *five seconds.*"

It is characteristic of the businesslike habits of the Hydrographic Office that they take no chances of mistakes in printed figures. In dim light or bad weather or heavy rolling a 3 and an 8 look much alike. So the *Sailing Directions* print everything in full in words, while the Chart compresses as much information as possible into a minimum of space. One is reminded of a similar instance of caution in the duplication, in words and in figures, of the amount for which a cheque is drawn. And indeed, in navigation, the value of the cheque is nothing less than that of a good ship and her freight of merchandise and of souls.

CHAPTER V

Machines and Instruments

THE LOG

The most primitive method of measuring the speed of a ship was to tie a line to a log of wood, drop the log overboard, and see how fast the line ran out. The name *log* is still applied to all machines for measuring speed, and the *hand-line* and *log-line* still survive.

The *log-ship* is fan-shaped and the curved edge is weighted so that it floats upright. The line is attached so that it sets the log-ship at right angles to it until a sharp pull frees one corner and allows the whole to be hauled on board again without much resistance. The line has its first mark 100 feet or more from the log-ship, and counting does not begin until

this *stray-line* has run out, and the log is clear of the *wake* of the ship, that is, the disturbed water astern.

After that the line is marked by knots which can be felt even in the dark. The number of knots which run out in 28 seconds measured by a sand-glass is the ship's speed in *knots*. Of course, all this used to be done by hand. Nowadays the line is on a reel fitted with a brake, and the glass is replaced by a watch. But so long as there are ships afloat, so long will the words *log* and *knot* survive.

A *knot* is a speed of one sea-mile per hour. A ship is said to "steam 20 knots," or to be "steaming at 20 knots," or to "have steam for 20 knots." But it is absolutely incorrect to write "20 knots an hour." A knot is not a length except on the log-line.

A sea-mile is the average length of one minute of arc of a great circle of the earth, namely 6080 *feet.*

A knot is a speed of one sea-mile per hour.

No one seems to know why 28 seconds was the interval of time used. But this being fixed, the length between two knots on the line is easily calculated. For—

Length in ft. : 28 sec. :: 6080 ft. : 1 hour $\therefore$ length $= 47\frac{1}{4}$ ft.

It is not probable that any reader will see the hand-log used. But it was worth while to describe it, simply to show how the words *log* and *knot* come to have their present meanings. It may be mentioned, in passing, that the hand-log is an excellent machine for finding the rate and direction of a current or tide-set from a ship at anchor.

Patent Logs have been invented almost in dozens. It would be invidious to single out any special pattern for description. The principle is the same in all, but details vary. Some sort of float is towed astern, having on it inclined fins or vanes like the blades of a screw propeller. As the ship proceeds, these revolve and the number of revolutions measures the distance run, on some fixed scale. At first the float itself contained counting mechanism, just like a cyclometer, and the log-line had to be hauled in to read it. This was inconvenient, and so the counter was placed on the ship, the revolutions being transmitted by a *plaited* cord which did not kink. Thus the dial can be read in miles and tenths at any moment, showing the

distance run from the time (generally noon) when the pointers were set to zero. There is often a bell which strikes at intervals, say quarter miles.

A further advance was to connect the counter electrically with a repeater on the bridge under the eye of the navigator. The "step-by-step" mechanism can be imagined, but would take many words to describe. There is thus a continuous record of the whole distance run from zero.

But it is often necessary (as in warships) to know the speed at the moment, without waiting to calculate it from the distance covered in a certain time. This need has produced another kind of log on a different principle. The rotating part is made to drive a tiny dynamo; and the voltage is proportional to the speed, which can be read on a voltmeter marked in knots.

Of course, all logs which are mechanical have errors which can be detected only by actual trial in runs made over a *measured mile*. This so-called mile is any measured distance ashore the start and finish of which is indicated by marks visible from the ship. These are generally beacons in line, and the course on which the ship has to steer during the trials is also marked and laid down. The "measured mile" in Weymouth West Bay is 8678 feet, for instance. This is an absolute distance, but it must not be forgotten that there is always more or less tidal current, and that what a log measures is the speed *through the water* and not the speed *over the bottom*. The question of currents and tides needs a separate section for proper discussion, (see p. 67), but the allowance for tide in testing logs may be considered here. It would seem reasonable to say that if in a set of six runs up and down, with and against the tide, the times for a mile were 4 min., 5 min., 4 min., 5 min., 4 min., 5 min., then the *average* time being $4\frac{1}{2}$ minutes, the *average* or true speed of the ship was 1 sea-mile in $4\frac{1}{2}$ minutes, or $13\frac{1}{3}$ knots. This would be wrong, as can easily be proved. A mile in 4 minutes is 15 knots; a mile in 5 minutes is 12 knots. So

$$\begin{aligned} \text{Speed of ship} + \text{speed of tide} &= 15 \text{ knots} \\ \text{Speed of ship} - \text{speed of tide} &= 12 \text{ knots} \\ \therefore \text{ Speed of ship} &= 13\tfrac{1}{2} \text{ knots} \\ \text{and speed of tide} &= 1\tfrac{1}{2} \text{ knots.} \end{aligned}$$

The difference, $\frac{1}{6}$ knot, may appear to be not worth worrying about. But where a navigator is constantly contending against odds of wind and weather and current, all of which are uncertain, he cannot afford to throw away any chance of accuracy. It is by trials such as these that proper percentage errors are assigned to each individual machine.

It is well recognised that one of the most reliable measures of speed is the actual revolutions per minute of the propellers of a steam-ship. Indicators are fitted on the bridge, in connection with the engine-room, counting the revolutions. It is known from the trials that a certain number of revolutions give a knot when the ship's bottom is clean. Experience and pure seamanship teach an officer what allowance to make for the growth of weed on the bottom, for the state of the sea and the weather. In the end, with all care and skill, it cannot be said with certainty, within two miles in a hundred, what the distance run by a ship has been. A cautious man approaching land will allow for a possible error of 1 in 20 miles *in the direction of danger*, as by imagining himself to be some miles nearer land than is shown by his reckoning, and then taking all precautions of sounding and looking out for lights. No ship has ever been lost through over-caution; most ships that have gone ashore have been navigated with over-confidence, born of long familiarity with danger.

COMPASS

Navigation without the compass would be mere coasting in sight of land. Man, unassisted by machines, has no sense of direction such as seems to be possessed by homing birds. It is true that, on shore, certain scout-knowledge enables one to find one's way by reading natural signs on trees; but when afloat in the middle of a sea horizon, there exists no means, except the compass, of continuously directing the ship's head.

The compass is then the first and essential requisite of the seaman.

Until recently it has been accepted in a vague and general way that the invention of the compass was due to the Chinese, to whom was ascribed also the earliest knowledge of printing

and explosives. It is much more probable that, as soon as the directive property of iron rubbed with the lodestone had been observed, then some primitive form of compass came into use in every part of the world where civilisation had advanced so far as to appreciate it.

But the instrument remained undeveloped and inaccurate up to the time when iron was first used for shipbuilding. Then, owing to the large errors introduced by the magnetism of the ship herself, the whole theory had to be investigated, and successive improvements resulted in a compass of precision. Later again, high speeds and consequent vibration demanded greater stability and strength, and a *liquid compass* was produced, where the directive part floats in liquid and is thus shielded from shock. Finally, the gyroscope has been adapted to direct the compass card.

The *compass card* shows the direction of visible objects within the horizon, as they would appear to an observer standing at its centre. At a given place and time a magnet needle is constrained to lie in a certain known direction, not generally horizontal, but *dipping* one way or the other. If the needle be fixed to a card and nicely balanced, it can be made to lie horizontal, and then the needle points to *magnetic north*. This is not generally the same as *true north*, which is the direction of the up-and-down meridians of the chart. But this does not matter, so long as the chart bears a compass drawn for the magnetic meridian. The compasses drawn on the plan of Plymouth and the chart of the approach to Plymouth show magnetic north 16° to the west of true north at the date of drawing them. The card of the compass on board is an exact replica of that on the chart. There can be no difficulty in understanding what is meant by a direction of N. 30° E. *magnetic*, or S. 42° E. *magnetic*; or in seeing that (at that place and time) these correspond to N. 14° E. *true* and S. 58° E. *true*.

But there is another way of reading the card—in *points* instead of degrees. This is a relic of old days when compasses were not sensitive, and a circle divided into 32 points was as accurate as might be trusted. It will be sufficient to indicate, in tabular form, the eight points in the quarter or *quadrant* from north to east.

Compass Points

Points . . .	0	1	2	3	4	5	6	7	8
Cardinal . .	N	—	—	—	—	—	—	—	E
Quadrantal .	—	—	—	—	NE	—	—	—	—
Intermediate .	—	—	NNE	—	—	—	ENE	—	—
By-points . .	—	N by E	—	NE by N	—	NE by E	—	E by N	—
Degrees . . .	0°	11¼°	22½°	33¾°	45°	56¼°	67½°	78¾°	90°

The process of successive halving is self-explanatory—*East-nor'-east* is obviously halfway between *east* and *north-east*. The *by-points* are reckoned from the more important of the two adjacent. One could hardly say "*East-nor'-east-by-east*" when "*east-by-north*" is available. It is possible to subdivide further into quarter-points, *e.g.* "*Nor'-east-by-east-quarter-east*"; but it is preferable to use degrees if such accuracy is needed. For estimating the direction of winds and currents the point-system is excellent, and it is somewhat curious that in the higher analysis of compass errors it proves to be most convenient.

The compass in general use is that designed by Lord Kelvin and known as *Thomson's Compass* in all languages. The card is extremely light, and the needles very lightly magnetised. The card is balanced on a jewelled centre, and consists of an aluminium rim, silk spokes and Chinese paper card. The silken radii give just enough to let the weight fall below the pivot, for stability.

The *liquid compass* is supplied to warships, instead of the Thomson's, because the heavy shocks of gun-firing proved too much for the delicate construction of the latter. In this the card is mica, the needles are round bar magnets in watertight cases, and the rotating part is floated inside a brass bowl completely filled with a mixture of spirit and water and covered by a glass top. A clear space exists all round the card, and the liquid absorbs most of the shock and vibration. The Thomson's bowl has no liquid, but otherwise the rest of the description to follow applies to either compass.

The bowl is slung on *gimbals* (which are practically a universal joint) so that the rolling or pitching of the ship has small effect. The gimbals fit into the top of the *binnacle*, a pedestal standing breast-high on the bridge. Inside this and around it are various compensators for freeing the needles from the effect of the magnetism of the ship herself. On top of the glass cover is an arrangement of prisms which enables the observer to see an object and the degrees of its bearing simultaneously and in the same line. The word *bearing* means direction, simply. A pointer or mark inside the bowl and close to the divided circle of the card shows the *ship's head* or fore-and-aft line. This is called the *lubber's point* or *lubber line*.

To steer the ship on any *course* (one speaks of the course of a ship, not her bearing), the lubber's point is kept on the graduation indicating that course; a skilled quartermaster can do this without much trouble, but a *lubber* has to be incessantly watching the mark.

It will now be understood how, by means of log and compass, a ship may be steered in any direction and the distance may be measured. The navigator knows his course and distance run from his starting-point, and can deduce his position at any time. This is his *Dead Reckoning.* The subject of Compass Errors cannot be treated satisfactorily except at length, but some general explanation must be given. It has been said that magnetic north is not generally the same as true north. The difference is called *Declination* by scientists ashore, but is always known as *Variation* among seamen. In our sketch charts the Variation for that time and place is 16° West. No more need be said, as the thing is evident on the figure. This variation cannot justly be called an *error*, for no more can be expected from a magnetic compass than that it should show magnetic north. There are World Charts of Magnetic Variation.

But the ship herself is permanently magnetic so far as her hard steel is concerned, and temporarily magnetic in her soft steel. It is well known that any steel bar held in a magnetic field is magnetised, especially if it is at the same time tapped so as to set its molecules freer to align themselves inside the metal. A ship when building is in the earth's field and is constantly hammered and shaken. Her hard steel becomes the equivalent of one huge magnet which tends to pull the needle round as the ship alters course. So in the binnacle are placed small magnets, lengthways, sideways, and up-and-down, to nullify the ship's effect in causing *Deviation* of the compass.

The soft steel loses its magnetism when the ship is launched and lies in another direction, but it is magnetised afresh as may be due to the new direction. It is found possible to fit compensating spheres and a vertical *Flinders* bar all of soft iron and near the compass so that their transient induced magnetism may exactly balance that of the ship. In this way the compass may be compensated and the deviation eliminated, within a degree. But there still remains the unfortunate fact

that steel cannot practically be separated into "hard" and "soft" varieties; and no compensation can be introduced for the effect of intermediate qualities of steel. Deviation did not trouble navigators until iron and steel were built into ships in large quantities. Flinders, the Antarctic explorer, introduced the vertical bar which bears his name. Airy, Astronomer-Royal, investigated the subject for the Admiralty and founded the mathematical theory. Poisson, a French scientist, did the same about the same time. Our *Admiralty Manual* (1862) contained the whole theory as edited by Archibald Smith, and this manual has provided material for works in many languages. Lord Kelvin brought his practical inventive genius to bear on the problem and produced the first compass of precision.

The *Gyro-compass* has nothing to do with magnetism. Everyone has played with a toy gyroscope or gyrostat, and has noticed its peculiar property of keeping its axis of rotation in a fixed direction unless the gimbals be touched. A more startling property is this: that when one tries to turn the axis in one direction it slips away in another direction at right angles both to the axis and the pressure applied. This is *precession.*

Take now a closed case containing a gyro made to rotate continuously at enormous speed by a three-phase alternating current. Float it in mercury or hang it by a torsionless strand so as to compel the axis to lie horizontally. As the earth rotates in space the horizon of the plane rotates also, supplying (*through the thing's own weight*) a turning force like the pressure of the finger just mentioned. The gyro precesses until its axis points *true* north, and when there it has no further tendency to precess. The rest of the fittings must be imagined; they are too complicated to describe in brief.

The Gyro-compass is not yet perfected, but more than one pattern is on the market, and it will soon be an essential fitting at any rate for warships.

The advance from the piece of lodestone floated on a cork to the gyro-compass is a measure of man's accumulated store of knowledge over some thousands of years. Yet since 1900 the writer has made a 24-hour passage in the Mediterranean in an open boat manned by Levantine fishermen whose only compass

consisted of a bowl of oil, a piece of cork, and a small bar magnet. Thus the ages meet.

THE SEXTANT

A sextant measures the angle formed at the observer's eye by two rays of light from two visible objects. One object is seen directly in a telescope; the other is seen by reflexion in a rotating mirror. The word *normal* is needed; it means the straight line perpendicular to a surface. A plumb-line hanging over water is normal to the water surface. A light ray re-

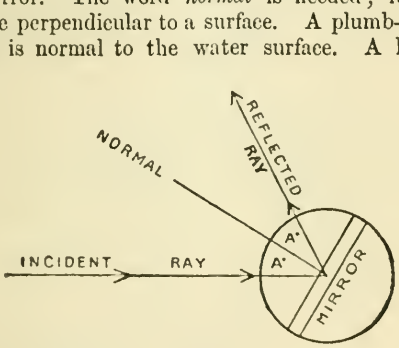


FIG. 5.

flected at a plane surface makes equal angles with the normal, at the point where it arrives and departs. If the ray is normal on incidence, it is reflected back along the normal.

Suppose the mirror is originally perpendicular to the incident ray, and then turn it (with its normal) through $A°$ of angle. The reflected ray departs $A°$ the other side of the displaced normal, so that altogether the *light ray turns twice as much as the mirror.*

Now consider the diagrammatic sketch of a sextant, Fig. 6. The frame is about a sixth of a circle, hence the name. A *direct* ray is shown, passing to the eye through the telescope. A *reflected ray* from another object, shown in broken line, strikes the mirror *I*, is reflected on to the mirror *H*, joins the direct ray, and so the eye sees both objects in one. The mirror *H*

is the *Horizon glass*, since the horizon is usually the direct object, and is seen through part of the mirror left unsilvered for that purpose. The mirror *I* is the *Index glass*, since it is fixed on to the index arm pivoted at the centre of the graduated arc. At *V* the smaller scale looking like a comb is a *Vernier* by which minute subdivisions of the arc can be read

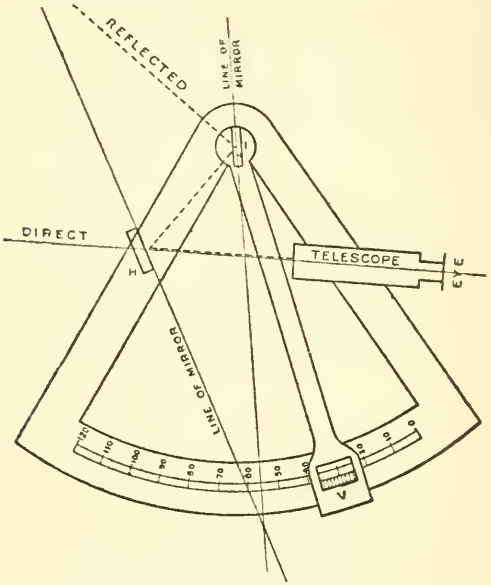


FIG. 6.

with the aid of a microscope. The fittings of clamps, slow-motion screws, shades, &c., are not drawn, as they would only obscure the main principle. When the direct and reflected rays are parallel, the vernier is made to read 0°, then in any other position the index arm has moved half as much as the reflected ray. Therefore, the number 10 is put at 5° of *real* angle on the arc, 20 at 10°, and so on, and the vernier reading is the angle between the objects.

Into the question of the various fittings and adjustments of the sextant it is not proposed to enter. It is a most delicate instrument needing the greatest care and skill in its use; but in good hands it is of marvellous accuracy, and of universal utility, since it requires no fixed supports, and can measure angles in any plane, while other purely astronomical or surveying instruments are confined to fixed directions. The sextant seems to have been invented almost simultaneously by John Hadley, an English country gentleman interested in optics, and by Thomas Godfrey, a working glazier in America, about 1730. Sir Isaac Newton had certainly imagined some such machine thirty years before, but had not put his ideas into practical form.

Sextants are tested at the Kew National Physical Laboratory, but this test is no guarantee of their *continuous* good performance, and the errors must be determined for each observation when great accuracy is required. In skilled and careful hands, such as those of the professional nautical surveyor, a first-class sextant will appreciate the angle between the two ends of a footrule at a distance of five miles.

THE CHRONOMETER

A chronometer differs from an ordinary watch only in the perfection of its mechanism and in the elaboration of its regulating part—the balance wheel and hair-spring.

The trouble is that all metals expand as the temperature rises; so, under heat, the balance wheel grows and acts as a longer pendulum, vibrating slower. Again, the hair-spring grows and also loses elasticity, making the chronometer lose. Here are two separate causes of error.

It will be seen in the chapter on Astronomical Navigation that longitude can be found simply and easily if Greenwich Mean Time is known, but not otherwise. In 1735 the Admiralty offered £20,000 reward for a reliable timekeeper. John Harrison, a Yorkshireman by birth and a mechanic of but small education except at his craft, won the prize after spending forty years on the work of experiment and improvement. The value of the invention may be realised from the fact

that on the return from a trial voyage, making a land-fall in the Channel, the point first seen was declared by Harrison to be the Lizard (by his chronometer), but by the master of the ship to be the Start (by older methods). Harrison was right.

The principle of compensation for temperature depends on the fact that two metals (say brass and steel) expand by different amounts. Thus a bar made of two strips, one of brass and one of steel, will *bend as it expands*. Harrison fitted such a bar so that its moving end "curbed" the hair-spring as temperature rose; that is, shortened its moving part and tended to make the balance wheel oscillate quicker. But the wheel itself expanded and tended to run slower, and the two effects *compensated* one another.

This was worth the £20,000, but did not end the trouble, for a single remedy was applied for two different ailments. Later inventors divided the rim of the wheel into two or more arcs, made the rim of two metals, and arranged things so that as the wheel grew bodily the ends of the arcs curved inwards and compensated the balance. Then the correction for the spring is made separately.

The discovery of the alloy *Invar*, which is scarcely affected by heat, as its name implies, is tending to perfect chronometers. By a perfect chronometer is meant one that runs day by day at a *steady* speed. It does not matter in the least if it gains 10 seconds a day regularly—this can be allowed for. But if it gains a second one day and loses two the next, irregularly, it is a bad timekeeper. The Observatory at Greenwich tests chronometers severely, observing their rate of losing or gaining under heat and cold and motion. All makers of repute compete in these trials, and the best machines are bought for the Navy. They are well cared for on board, being kept in padded nests well shielded from shock and vibration, and at a uniform temperature as far as possible. Their accuracy is remarkable; that is to say, their *rate* is all but uniform. After allowing for rate, Greenwich Mean Time is obtainable within two seconds ten days after leaving port. The introduction of time-signals made by wireless telegraphy at stated times enables the navigator to check his chronometers. There are also *Time Balls* at most ports. These are hoisted on a mast visible at a considerable distance, and are let fall at some

known instant of G.M.T. by electrical gear. Of late the increasing use of electricity on board ship has been found to introduce magnetic errors. These have been investigated, and it has been recommended to enclose the chronometer in a heavy box of soft iron, which forms a magnetic shield.

But chronometers are now so reliable that, without further discussion of errors, it will be assumed that "G.M.T.," Greenwich Mean Time, is carried as part of the outfit of a ship.

CHAPTER VI

Winds, Currents, and Tides

WINDS

Into the details of winds and ocean currents it is not proposed to enter. The volume *Weather* of this series treats of them in detail, and the navigator does not concern himself with causes so much as with dealing with the actual circumstances which arise. To meet his requirements the Hydrographic Office publishes *Wind and Current Charts*, which record the average circumstances to be expected, month by month, at any place. The *Sailing Directions* give similar information.

A few general remarks may not be amiss in explanation of terms used. A weather forecast as published in the newspapers, or as communicated by wireless telegraphy to ships at sea, contains, as a rule, the words *cyclonic* and *anticyclonic*. A cyclonic wind surrounds an area of low barometric pressure, an anticyclonic wind one of high pressure. The air flows inwards, naturally, towards the low-pressure point, and outwards from the high-pressure point. In so doing it is deflected by *Ferrel's law*, which needs to be stated.

It was explained that parallels of latitude were of different lengths, longest at the equator and decreasing towards the poles. Every point of the earth rotates once a day, so a point on the equator moves faster than any other, and a point on any parallel moves faster than a point on another parallel nearer the pole of that hemisphere.

Now start anything moving on the surface: it must move towards or away from the nearer pole. But it preserves also the velocity of the parallel whence it started, which is not the same as that where it is arriving. A train travelling due *north* from London presses more heavily on the *eastern* rail. A projectile shot due *south* from a gun in Australia wanders to the *east* from its line of aim. Interchange the words north and south, and the deflection tends to the west in both cases.

Ferrel's law applies this to wind moving always from high to low pressure areas. Take a cyclone in the north hemisphere. North of the centre air flows southward *and to the west*, south of the centre it flows northward *and to the east*. The total effect is a spiral motion against the clock and inwards. The other cases are summed up in the table:

Hemisphere.	Cyclone.	Anticyclone.
North . .	Against clock	With clock
South . .	With clock	Against clock

It is advisable, at any rate for a sailing ship, to get away from the centre of abnormal pressure. *Buys-Ballot's law* is derived from Ferrel's and is learned by all seamen.

Face the wind. The low-pressure area is on your right in the north hemisphere, but on your left in the south.

The wind "changes" as a cyclone or anticyclone passes over the ship. It *veers* when the point from which it blows moves with the clock, and *backs* in the contrary direction.

Revolving storms are all cyclonic, but are called *hurricanes* in the West Indies and Pacific, *typhoons* in the China Seas, and *cyclones* only in the Indian Ocean.

Prevailing winds are due to the heat of the sun, which establishes more or less permanent areas of low pressure. These result in the *trade-winds* of the Atlantic and Pacific, and in the *monsoons* of the China Seas and Indian Ocean. The *doldrums* are an equatorial belt of calms, where Ferrel's law has no opportunity of producing effect and the sun's heat is nearly uniform.

There would be no point in giving details of local winds, as these could not be remembered and in any case are to be found in the books and charts already mentioned. But the statement of the general laws is of considerable interest. The wind does not "blow where it listeth," but is subject to natural laws which are more and more being reduced to an ordered scheme. Weather forecasts have passed the stage of Old Moore's Almanac, and have entered that of scientific prediction.

CURRENTS

The systematic observation of the circulation of ocean water has been possible since the time of chronometers. Suppose a ship knows her course and distance *through the water* from a fixed point, by dead reckoning. After a certain time she knows she ought to be at another spot. But if astronomical observations prove that she is not there, then the water itself must have moved, and an ocean current exists. These are recorded, and the *Wind and Current Charts*, &c., already mentioned, contain the results. The general ideas of the causes of currents may be explained without details.

First, every prevailing wind causes its own *drift current*. It must be stated that currents are specified by the directions *towards which they set*, in distinction from winds as named from the quarter *from which they blow*. A north-east trade-wind should produce a south-westerly surface-drift current, and does tend to do so.

Second, there is the great thermal circulation of the ocean as a continuous body of water. The Atlantic, Pacific, and Indian Oceans are in reality gulfs running northwards from the Antarctic. Ice is, of course, not salt, and when it melts it becomes fresh water, *lighter* and *colder* than average sea water. Part of this floats on and dilutes the surface water and goes away as a surface current. Part chills the deeper sea water, rendering it denser so that the bottom waters subside. Intermediately there must be a current towards the ice to restore equilibrium. All these movements are subject to Ferrel's law, so the resultant effects are complicated. In any case there is

a surface *stream current* generated, and a cold *creep* at the bottom, and an intermediate current.

Third, when surface drifts are headed or banked up against land by prevailing winds the water must get away somehow to restore the general level. It does this in a low-level *counter*-current which must appear somewhere.

A fair example of the general theory is found in the Atlantic. The trade-winds cause two westward drifts just above and below the equator, and between them appears the equatorial counter-current. The southern drift divides on reaching the American coast, part of it goes down south as the Brazil Stream current, the other part joins the north drift and piles up in the Gulf of Mexico. There arises the Gulf Stream current of warmer equatorial water up the coast of North America. Its future course cannot here be described. The point to be noticed is that two *stream* currents arise from two *drifts*. But if a stream of water is being removed there must be water coming in to fill the void, and this appears as colder water from the bottom, most conspicuous in the "cold wall" between the North American coast and the main Gulf Stream.

This brief sketch of principles must suffice. The volume *Weather* of this series should be consulted for details. At any rate the reader will no longer be satisfied with statements such as those now extracted from a standard text-book on geography: "The Gulf Stream has a natural tendency to flow due north." "The water in the Tropics is heated to a greater extent than the rest of the ocean, and becomes lighter; consequently it rises to the surface."

The Gulf Stream does not flow north because it is warmer than the Atlantic, it is warmer because it comes from the equator. It flows north-east, and the Brazil Stream flows south-east, simply because the level of the water in the Gulf of Mexico is about three feet higher than the average owing to the equatorial drifts.

TIDES

The tides of northern Europe are very fairly regular, and will serve to introduce the subject. The sea-level alternates between high water (H.W.) and low water (L.W.) on either side

of mean water or half-tide level, with a period (H.W. to H.W.) averaging $12\frac{3}{7}$ hours for a complete tide. The course of a tide is represented, on the average, by a simple harmonic wave, easily derived from a tidal "clock-figure," as shown in the diagram. The horizontal scale of time shows twelfths of a period, not much different from hours. The water-level at any "hour" is the same as the level of that "hour" on the clock, supposing the clock to keep time with the tide.

This is not strictly true; for two successive high waters are not necessarily of the same height, and low water of a tide is not necessarily as much below the mean level as high water is above it. But for most practical purposes, reckoning from a high water for six hours either way, it serves quite well. The *Tide Tables* give the times and heights above datum of all high

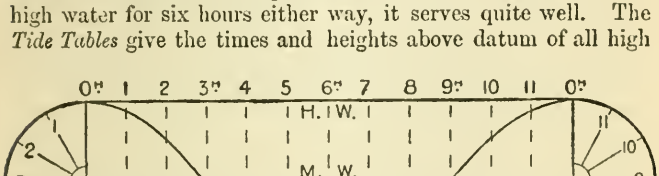


FIG. 7.—Simple Harmonic Tide Wave.

waters and of some low waters; and also the height of mean water above datum under the name of *half mean spring range*, a term which will be explained later. Then the height at any other time can be deduced by the following simple rule:

In the 1st, 2nd, 3rd sixth of the time between high and low water rising or falling, the water-level changes 1, 2, 3 *sixths of the half range.*

For example, suppose that at some place there were given:

High water at $2^h\ 15^m$ P.M. rises 18 feet,
Half mean spring range rises 12 feet,
Tide rises in 5^h, falls in $7^h\ 30^m$,

then the depth above datum, namely, that of soundings on the chart, could be predicted for the day. The half range of the tide is six feet, the one-sixth of rising is 50 minutes, the

one-sixth of falling is $1^h\ 15^m$. Working backwards and forwards from high water we have:

Time.	Height.	Time.
H.W. 2.15 P.M.	12+6=18 feet	2.15 P.M. H.W.
1.25 ,,	12+5=17 ,,	3.30 ,,
0.35 ,,	12+3=15 ,,	4.45 ,,
M.W. 11.45 A.M.	12 =12 ,,	6.00 ,, M.W.
10.55 ,,	12−3= 9 ,,	7.15 ,,
10.05 ,,	12−5= 7 ,,	8.30 ,,
L.W. 9.15 ,,	12−6= 6 ,,	9.45 ,, L.W.

And if the chart showed eight-foot soundings in a channel where it was required to pass in not less than 25 feet of water, the time table indicates that there will be that depth available between 1.25 P.M. and 3.30 P.M. Or again, if the depth of water over a rock, marked six feet on the chart, were required at 4 P.M., it is seen to be $(6+15\frac{1}{2}=)\ 21\frac{1}{2}$ feet about.

The two preceding problems are those which practically arise. The simple rule given and the *Tide Tables* make them easy to solve. Of course if the time and height of low water be also given, then by working only three hours on either side of both high and low water greater accuracy is obtained.

The next point to be considered is the tidal currents which attend on the tide. It must be clearly understood that in a wave there is not any actual displacement of a crest of water along the surface. A wave is a periodic change of *state*, not of *matter*. In the tide wave the *state* is distance of surface above or below mean water, and the same state travels half round the earth in $12\frac{2}{7}$ hours. The water does not travel. But any given particle of water oscillates about its mean position, its direction of separation being towards that figure on the clock which shows the state of the tide at the moment. This small oscillation is a real tide current, but it is hardly perceptible. It accounts for the defect of water in the hollow and the excess at the crest by the crowding of particles towards high water, although they never move far in their crowding. In the same way there is great pressure, or high water of humanity, at a

theatre door just opened, although the individuals in the *queue* may none of them have moved more than a pace or so. At the end of the *queue* the files are open, in low water of the crowd.

The great ocean wave travels thus until the depth of water lessens on nearing a coast. As soon as the disturbed water touches bottom, that part of it is retarded and the wave loses its simple character. The surface breaks up, especially if there be wind and uneven bottom, and the tide comes in as rollers and ripples and crested "waves" in the ordinary sense. But these are not tide waves, they are merely symptoms of the change of state of water-level nearing and impinging on the land. In V-shaped channels the rising water must rise still more as it narrows, becoming sometimes a *bore* or wall of water rushing inwards. This may even run up stream as a salt-water layer, while the fresh-river water still runs seaward underneath. It is not strange, then, that the currents due to the tides should be most complex. The landward *flood* and seaward *ebb* of the tidal stream need not coincide with the *rise* and *fall* of the sea-level, but may be half a tide behind. And where there is more than one entrance to an anchorage or harbour there may be interference of separate streams. Obviously, therefore, these are matters of local observation and experience. The charts and sailing directions summarise the knowledge which is available, and by reference to them the probable speed and direction of the tidal stream may be found for any place at any time after high water. The actual tide wave is built up of several component waves. The theory cannot be explained here; the results must be accepted as true. Were the moon in the equator at a constant distance and constant speed she would produce a wave as described, of period $12\frac{3}{7}$ hours, and of half range or amplitude determined by observation—the *principal lunar tide*. But since she moves north and south of the equator in her monthly orbit, there is also a tide of $24\frac{6}{7}$ hours' period on the average. This is a *declinational tide*. Again her distance varies, and the magnitude of her tide effect varies in consequence. The variation is allowed for by a *parallactic* tide. Differences in speed are included by superposing other waves of proper period. The sun's tide effects are similarly treated.

This is really a most inadequate statement but must serve. The mathematician will understand that what is done is to express the variation from mean sea-level by a Fourier series of terms such as

$$h = H.\cos(2\pi t/T - \mathrm{E})$$

where H is the amplitude of any simple wave, T its period in hours, t the hours elapsed from some zero, and E the *epoch* of the wave. The *epoch* is introduced to adjust for the fact that the high water of the wave does not necessarily correspond to zero time. Thus the lunar high water occurs some two days after the meridian passage of the moon causing it. The tide is said to be two days old in such a case, and the odd hours of delay after the preceding transit is the *lunitidal interval* of that tide. The average lunitidal interval is the *Establishment of the Port*, always written H.W., F. & C., for *High Water, Full and Change*, since at new and full moon the actual interval is the average interval.

The diagrams show, graphically, how the waves are combined (Fig 8).

In *A* a 12-hour tide of 5 (• —— • ——) is affected by a 24-hour tide of 3 (• • • •). The result is a *lesser* high water of 2 midway between two of 8 each. The two low waters are of 5.1 each, *displaced* towards the middle line, so that the lesser high water has also less time of rise and fall.

In *B* the values are interchanged and the lesser high water almost vanishes, while the low waters are much more disturbed in time. It can be understood that if in any place the 24-hour tide were predominant there would be single-day tides. This actually occurs, and the reason is now plain. But in general the diurnal tide is only very small.

The solar tide has a period of 12 hours, the lunar period is $12\frac{2}{7}$ hours, so that there are only 28 lunar tides to 29 solar. The two waves combine to form another, the *principal lunisolar tide*, proceeding from *spring tide* with crest on crest to *neap tide* with hollow on crest, in 14 tides, and thence again to springs with hollow on hollow. Of course springs are due to the coincidence of the waves when sun, moon, and earth are in line at full and new moon; neaps occur when sun, earth, and moon form a right angle and the moon passes the meridian at

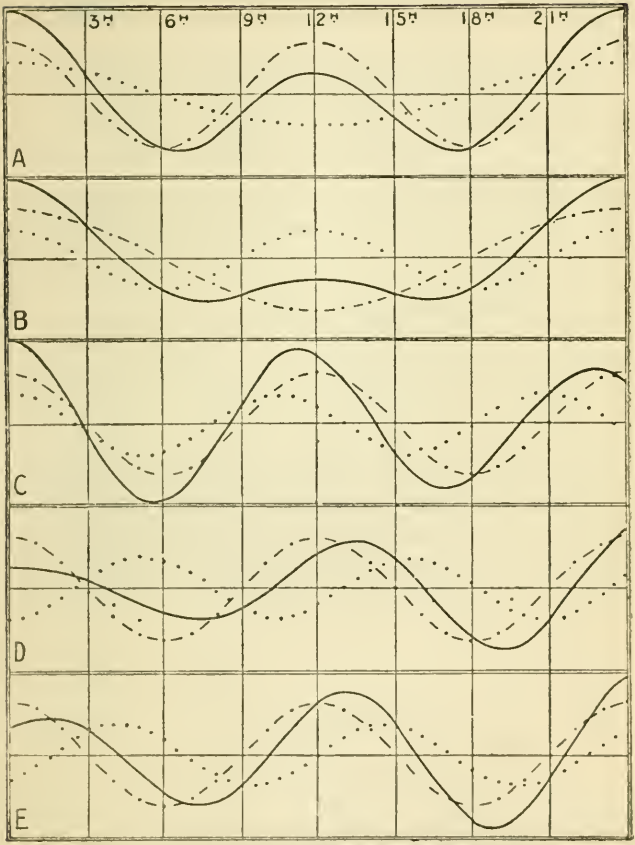


FIG. 8.—Compound Harmonic Tide Waves.

6 o'clock A.M. or P.M. So the hour of the moon's transit is a convenient reference hour for tabulating tides. The diagrams *C*, *D*, *E* show two waves of different periods combined. The disparity of period has been exaggerated to show the distortion better.

At *C* is shown the lunar crest on the solar crest, the lunar period being divided into 12 *lunar* hours. This is springs. The next high water is visibly less and is in advance of its proper place. The tide *primes* from springs to neaps, coming earlier than the average.

At *D* is crest on hollow, or neaps. The heights increase visibly, and the tide *lags* or comes later than is due from neaps to springs.

At *E* is crest on zero at the middle line. This is the position midway from neaps to springs.

The object of this section will have been attained if the reader has grasped in some degree the elegance and power of this harmonic analysis of tides as suggested by Lord Kelvin, and carried out by Sir George Darwin in particular among other workers. The comparatively simple curves resulting from the combination of *two* waves only show a very fair range of variety. An extension of the method enables the computer to take any tide record however intricate and to separate, one by one, each constituent. A full analysis takes count of some forty of these, and when they are once found the course of the tides can be predicted for any future date. The *Tide Tables* are thus constructed for the use of seamen.

CHAPTER VII

Dead Reckoning

As soon as a ship is out of sight of land, she must rely on compass to steer by, log to give the distance run, and "*reckoning*" or calculations to know where she is situated at any time. But why reckoning should be called "*dead*" is not clear. The phrase "*le point estimé*" is more lucid, as estimation of current is an important factor in the reckoning.

So long as the points of departure and destination or arrival are within reasonable distance on the chart, actual plotting and measurement serves all purposes. These purposes are two, namely:

(1) To find the course to steer by compass to arrive at a destination, and also the distance to be covered.
(2) Having started, then, at any future time, to find where the ship has arrived.

It has been explained in the section on charts that it is impossible to represent accurately on a flat surface any part of the earth's spherical surface. So of the two quantities involved, latitude and longitude, one only can be drawn uniformly on a chart, the other will vary as latitude varies. The two charts (Figs. 9 and 10) show this. The left-hand page has a uniform scale of latitude, and therefore the meridians converge towards the higher latitude.[1] The scale of longitude is perceptibly smaller at top than at bottom. This is the principle of the ordinary map, and on it objects are seen in the direction in which they lie on the map. The "plan" of Plymouth already described is drawn thus. But the peculiarity of a ship's track is that it makes a constant angle with the meridians in turn as it crosses them, the angle being the *course*. So the track on a constant course between *O* and *X* is not straight on this map but is concave upwards, as may be seen by looking along the line. Yet the point *X* if visible would be seen from *O* along the direct line. Here then is a paradox, that in order to arrive at a place by steering a constant course this course must not be in the line in which the destination actually lies. The track or constant course is (scientifically) a *loxodromic curve* (λοξός, oblique), and in seaman-like language a *rhumbline*. The shortest or direct track is an *orthodromic curve* (ὀρθός, straight) or *great circle*.

There is but little difference between the two for distances up to 600 miles, but for long voyages the matter is important and will be considered. The great convenience of being able to draw one's track as a straight line and follow it as such leads to the universal use of *Mercator Charts*, as shown on the right-

[1] The very high latitudes have been chosen so as to show a perceptible convergence.

hand page (Fig. 10). The scale of longitude at the bottom is the same as before, but it is continued uniformly all over the chart. Consequently the upper portions of the chart are seen to have a scale of latitude visibly larger than at the bottom.

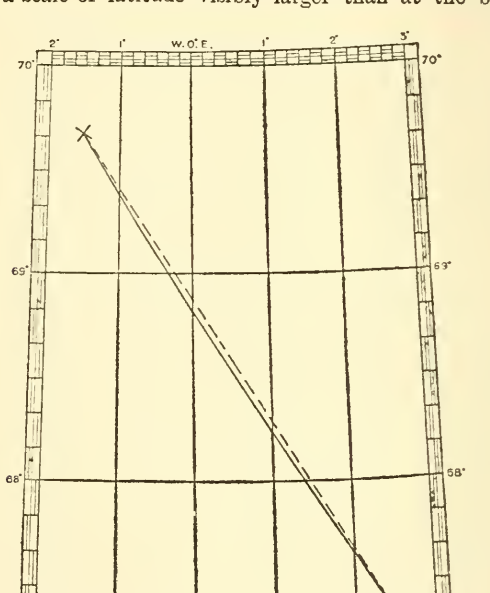


FIG. 9.—Map on Uniform Scale of Latitude.

The theory cannot be outlined without mathematics. In general language the left-hand map shows that the ratio of 1° latitude to 1° longitude on the earth increases as latitude increases. If, then, longitude be kept constant, the length of 1° latitude on the chart must continually increase towards the poles.

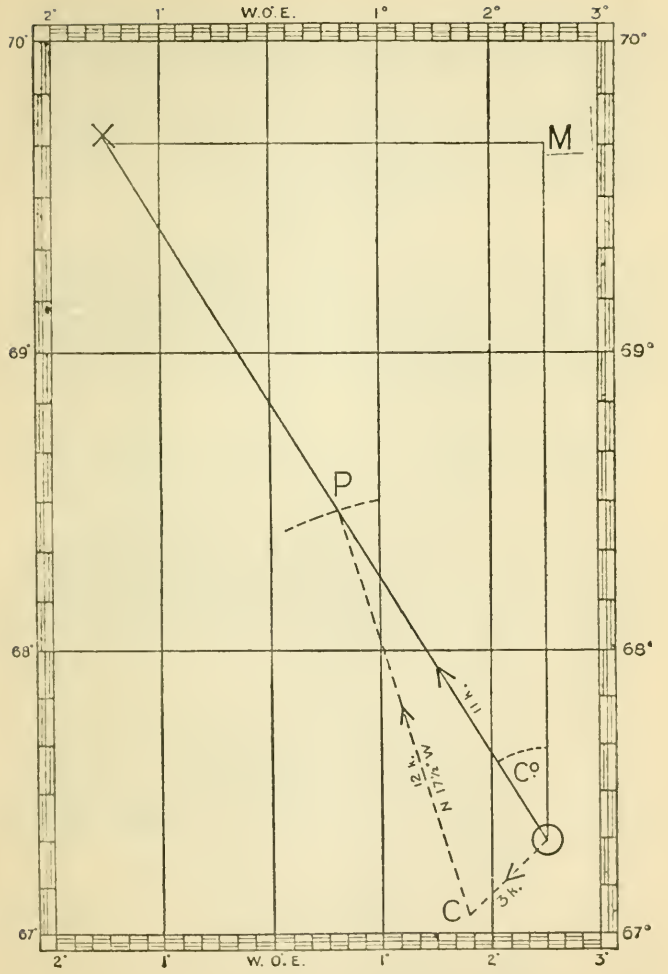


FIG. 10.—Chart on Uniform Scale of Longitude.

In symbols let dl be an element of latitude, and dp an element of a parallel in latitude l, sides of a small rectangle. The ratio of the whole length of the parallel to that of the equator is cos l. If dp be expanded to the length of its equivalent length on the equator, it must become dp sec l, and to preserve the scale dl must become dl sec l. Then the whole length m on the chart from equator to latitude l along the meridian is got by integrating the equation

$$dm = \sec l.\ dl.$$

The mathematician will recognise the solution as involving the Gudermannian function which here finds everyday use at sea, although very few seamen have ever heard of it. Practically the result is tabulated as "*Mercatorial parts for latitude.*" To draw the chart between 67° and 70° of north latitudes the tables were consulted and gave

mer. 70° = 5966	171 ÷ 50 = 3·42 inches
mer. 69° = 5795	164 ÷ 50 = 3·28 ,,
mer. 68° = 5631	157 ÷ 50 = 3·14 ,,
mer. 67° = 5474	

the unit being the minute of longitude. The chart was made on a scale of 1·2 inches to a degree of longitude, so division of the differences by 50 gave lengths in inches for each degree. The plate was then made half-size.

Suppose now the problem were:

To find course and distance from O in 67° 20′ N., 2° 30′ E., to *X* in 69° 41′ N., 1° 30′ W.

For so short a distance ruler and dividers and protractor would be used, and the results would be got at once, namely:

True C°, N. 32° W.; distance 166′.

But the calculation as now made would hold for *any* distance. It is simply the solution of the triangle *OM* by plane trigonometry.

Now OM = mer. 69° 41′ N. − mer. 67° 20′ N.
= 5911 − 5526 = 385
(from the Tables),

and MX = 1° 30′ W. − 2° 30′ E. = 240,

so $\tan MOX = 240/385$,

and course = N. 32° W.

The nearest degree is all that is practically useful. Of course logarithms are used to shorten the work. Next, for distance. Here the Mercator chart must be inaccurate except when only a small area is concerned. Recourse must be had to the map where the scale of latitude is uniform, since the sea mile is 1′ of latitude. On the map it is clear that for any and every 1′ of distance run the difference of latitude is 1′ × cos C°. Therefore, in the case in question:

$$\begin{aligned}\text{distance} &= (69^\circ\ 40'\ \text{N.} - 67^\circ\ 20'\ \text{N})\ \sec C^\circ \\ &= 140 \times \sec 32^\circ \\ &= 166'.\end{aligned}$$

This method of finding course and distance to a destination is known as *Mercator Sailing*. The principle was enunciated, and the necessary tables first published in an approximate form, by Gerhard Kremer, a map-maker of Amsterdam, in 1568. His name was latinised (as was then usual) into Gerardus Mercator, and the nautical chart derives its title thence. The theory was due to Edward Wright, a Cambridge mathematician (1590).

As an example of the converse problem, take:

To find the position after steaming 166′, *N.*32° *W. true, from O in* 67° 20′ *N.*, 2° 30′ *E.*

It is clear that, on any course in general, a certain difference of latitude (northing or southing), and a certain easting or westing must result. These are measured in sea miles, and the latter is technically known as *Departure*. Departure is related to difference of longitude by the formula already stated, namely:

$$\text{diff. Long.} = \text{Dep.} \times \sec \text{Lat.}$$

where the abbreviations explain themselves.

Again, for any small length of the track over which it is practically straight the distance is resolved into:

$$\begin{aligned}\text{diff. Lat. (N. or S.)} &= \text{Dist.} \times \cos C^\circ, \\ \text{Dep. (E. or W.)} &= \text{Dist.} \times \sin C^\circ;\end{aligned}$$

and these are tabulated in a table called the *Traverse Table* Consulting it the results are:

$$166',\ \text{N. } 32^\circ\ \text{W.} \equiv \left\{\begin{matrix}141' & \text{N.} \\ 88' & \text{W.}\end{matrix}\right\} \text{ sea miles.}$$

The latitude arrived at is therefore:

$$\begin{aligned}\text{Lat.} &= 67^\circ\ 20'\ \text{N.} + 141'\ \text{N.}\\ &= 67^\circ\ 20'\ \text{N.} + 2^\circ\ 21'\ \text{N.}\\ &= 69^\circ\ 41'\ \text{N.}\end{aligned}$$

The departure of 88′ along the parallels of 67° 20′ and 69° 41′ would be equivalent to quite different difference of longitude. Tables are made to convert departure into its equivalent longitude for any latitude. Consulting these:

$$\begin{aligned}\text{for } 88' \text{ in } 67^\circ\ 20', \text{ diff. Long.} &= 228,\\ 69^\circ\ 41' \quad ,, \quad ,, \quad &= 253,\end{aligned}$$

a big difference. But if the average latitude be used, midway between 67° 20′ and 69° 41′, namely, the *Middle Latitude* $68\frac{1}{2}^\circ$, the result will be as nearly correct as may be. For Dep. 88′ in Mid-Lat. $68\frac{1}{2}^\circ$, diff. Long. = 240′, and the longitude arrived at is

$$\begin{aligned}\text{Long.} &= 2^\circ\ 30'\ \text{E.} + 240'\ \text{W.}\\ &= 2^\circ\ 30'\ \text{E.} + 4^\circ\ \text{W.}\\ &= 1^\circ\ 30'\ \text{W.}\end{aligned}$$

This calculation is known as *Plane Sailing,* using the Traverse Table and Middle-Latitude Table, whence also it may be called Traverse Sailing or Middle-Latitude Sailing. It may be hoped that the explanation given has made the method all "Plain sailing" to the reader, exposing at the same time a common error in spelling! The word is *plane,* not *plain,* and its meaning is that, so far, we have derived formulæ from flat or plane maps and charts. It should be noted in passing that by reversing the steps of the last computation, the course and distance from O to X are immediately obtainable by the mere inspection of the tables mentioned.

Now we must pass from plane to spherical sailing. If it be true, as we have seen, that the rhumbline track is not the shortest track, then economy of time and coal demands a knowledge of the shortest way from port to port. This needs spherical trigonometry, and the unmathematical reader must skip calculations but may quite easily understand the principles involved.

Take an ordinary globe and mark two ports on it with pins. Stretch a piece of elastic between the pins and it takes up a

definite position, which is seen to be the *great circle* joining them in the plane containing both points and the centre. This must be the shortest route. Mathematically the great circle has the largest radius of any circle of the sphere, therefore it is flattest or nearest to a straight line, therefore it is the shortest route.

Next it is common sense that if on a plane one draws two lines of given length and including a given angle, from a point, then the third side is determined and is calculable. Also that if three sides of a triangle are known, the three angles are calculable.

The same things are true for spherical triangles formed by great-circle arcs joining three points on a sphere: and, of course, 1′ of great-circle arc is a sea mile.

Let the problem be:

Find the shortest distance from Three Kings, N.Z., in 33° 50′ *S.*, 172° 2′ *E., to off Cape Horn in* 56° 40′ *S.*, 68° 55′ *W. Find also the course on which to start the voyage.*

The triangle used has its apex at the nearer or south pole, where the angle between the lengths of meridian from the pole to the two places is simply the difference of longitude. The two sides are the defects of the latitudes from 90°. We have to find the third side and the angle at Three Kings. The work is given without comment, using the logarithmic formulæ of Hall's *Appendix to Raper's Tables:*

Computation of Distance

Three Kings .	172° 2′ E.		
Cape Horn .	68° 55′ W.		
Diff. LONG.	119° 03′ E.	L. ver . . .	0.1719
Three Kings	33° 50′ S.	L. cos . . .	9.9194
Cape Horn .	56° 40′ S.	L. cos . . .	9.7400
		L. ver . . .	9.8313
		N. ver . . .	.6782
Diff. LAT. . .	22° 50′ S.	N. ver . . .	.0784
DIST. . . .	75° 55′	N. ver . . .	.7566

This means a distance of 4555 sea miles.

Computation of Angle

33° 50′	L. sec . . . 0.081
14° 5′	L. sec . . . 0.013
19° 45′	
33° 20′	
13° 35′	½ L. ver . . . 4.223
53° 5′	½ L. ver . . . 4.801
29° 41′	L. ver . . . 9.118

This means a course of S. 30° E.

After a day's run the course would be re-calculated from the new position, altering day by day so as to keep to the curved path which is paradoxically the shortest way. As a matter of interest the Mercator course and distance are :

S. $74\frac{1}{2}°$ E., 5112 miles.

The gain of distance due to taking the short cut is thus (5112 − 4555 =) 557 miles, a matter of importance.

It should be remarked that there exist various graphical or tabulated aids to finding great-circle courses and distances by inspection, thus avoiding the calculations to some extent.

An interesting and important problem is the allowance for current in shaping a course. Suppose that on the Mercator chart (p. 77), where the track from *O* to *X* is laid down, it were known from the *Winds and Currents Charts* that a 3-knot current was to be expected, setting SW. true, while the ship was to steam 12 knots. It is clear that she must shape a course more to the north to allow for it. The amount of allowance is found graphically,

The 3 knots SW. is set off from *O* to *C* on any scale, the 12 knots is fitted in as at *CP* to the same scale, giving a course of N. $17\frac{1}{2}°$ W. to steer. Measurement of *OP* shows that only 11 knots will be *made good* along the track from *O* to *X*, as is reasonable since the current is against the ship.

The general and unmathematical reader must pardon the introduction of arithmetical calculations. Even if he has had to skip them he will have been able to understand their nature and the kind of problem which presents itself. The skilled

navigator is skilled in that he decides what may be neglected and what must be computed exactly; and in that he uses discretion to save labour, availing himself of short cuts and graphical methods when they are accurate in accordance to his needs.

The whole result of dead reckoning is this: Starting from a known position, and steaming on known course and speed, with allowance for current if any, the ship's place can be estimated at any future time. But it is not safe to assume that the dead-reckoning point is correct. Errors may exist in course and speed and in current, and they may accumulate to set the ship some miles away from the position by estimation. Therefore it is convenient to draw a circle about the point, of radius (about) a mile for every twenty miles of run, and to remember the possible error. The ship may be said to be located with high probability within this circle of doubt.

CHAPTER VIII

Astronomical Navigation

Technical terms are, in some sort, the tools of the scientific worker. Most of the difficulty of a subject vanishes when the use and meaning of its special vocabulary are understood. This is emphatically the case in the astronomy which is necessary for navigation, and the trouble is that by no means can anyone evolve from his inner consciousness an *à priori* notion of right ascension or parallax. But luckily all that is essential (apart from general knowledge of and general interest in astronomy) is a clear conception of the *elements* of the sun, moon, stars, and planets which are predicted in the *Nautical Almanac*.

This is an unpretentious and business-like little volume of some 200 pages published by order of the Admiralty. The *Astronomical Ephemeris* from which the *Almanac* is reduced is more bulky, containing data for the astronomer's use which are not immediately useful at sea. A page of extracts is printed on p. 85, and this may form subject matter for

explanation. It should be noted in passing that the date of the page is January 1914, while this chapter is written in July 1912. If man were entitled to boast himself, he might do so with reason on the supremacy of his mind, which can predict for years in advance the motions of bodies immeasurably remote and intangible save by the intellect which sees the universe steadily and sees it whole, a cosmos guided by unerring law. But on such thoughts would supervene the confession that the *why* is unknown although the *how* be familiar, and that man dwindles to the infinitesimal in his contemplation of the worlds of light whose rays he uses as guides in his seafaring.

The left-hand column or *argument* is G.M.T., Greenwich mean time. This must be defined with accuracy later on; for the present it must be admitted that G.M.T. is carried in the chronometer or deck watch.

The other columns are *elements* of the sun, of two bright stars, and of the moon at certain instants of G.M.T. They all change with time.

Without troubling about meanings for the moment, suppose that the sun's elements were wanted for the date Jan. 1914, $1^d\ 2^h\ 15^m$ G.M.T.

The DEC. is given at every even hour, and between 2^h and 4^h it decreases by 0.4′. At $2^h\ 15^m$ it will have decreased by 0.05′, and is therefore S. 23° 3.0′ as near as may be.

The EQN. increases 2.4^s in the two hours, or 0.3^s in fifteen minutes, and is therefore $+3^m\ 30^s$ to the nearest second.

This process is called *interpolation*, and it is clear that the value of any element at any time can be interpolated from the *Almanac*.

For instance, at $6^h\ 10^m$ G.M.T. of the same day, the right ascension of the mean sun is

$$18^h\ 42^m\ 9.3^s + \tfrac{1}{12}\,(19.8) = 18^h\ 42^m\ 11^s.$$

The elements of the stars change very slowly, those of the moon very quickly, but the principle is the same. It will be assumed in future that values can be found for a given G.M.T.

To understand the meanings of the names the reader must imagine himself to be posted at the earth's centre with a pair

Nautical Almanac, 1914

G.M.T.	The Sun.					
	Thursday, Jan. 1.					
	Right Ascension Mean Sun.			Apparent Declination.		Equation of Time.	
h	h	m	s			m	s
0	18	41	10.2	S. 23°	3′.4	+3	27·2
2	18	41	29.9	23°	3′.0	3	29·6
4	18	41	49.6	23°	2′.6	3	32·0
6	18	42	9.3	23°	2′.2	3	34·4
8	18	42	29.1	23°	1′.8	3	36·8

Date.	Stars.			
	α Arietis (*Hamel*).		α Tauri (*Aldebaran*).	
	R.-A.	Dec. N.	R.-A.	Dec. N.
	h m		h m	
	2 2	23°	4 30	16°
Jan. 1	19.9^{s}	3.6′	60.5^{s}	20.4′
April 1	18.9	3.5′	59.4	20.4′

G.M.T.	Moon.					
	Thursday, Jan. 1.					
	R.-A.			Dec.		
h	h	m	s			
0	22	37	6	S. 9°	40′.4	
2	22	40	44^{218}	9°	$13'.1^{273}$	
4	22	44	21^{217}	8°	$45'.7^{274}$	
6	22	47	58^{217}	8°	$18'.1^{276}$	

of Sam Weller's patent-double-million-power-magnifying-microscopes instead of eyes. Then standing with head to north pole and feet to south, along the earth's axis, he would see each astronomical body *apparently* occupying some definite position, for a definite instant, on the earth's surface If, further, the parallels and meridians were visible, he could say that the *apparent place* of a body was a certain latitude and longitude. As a matter of fact the words latitude and longitude have another meaning in pure astronomy, but no seaman uses them except to mean *geographical* position on the earth.

In this sense, then, *declination* is the apparent geographical latitude of the body. Where the body has a visible disc, as in the case of the sun or moon, the centre is the point of reference. The radius of the disc is its *semi-diameter* which is given in the Almanac. The rim of the disc is called the *limb*, specified as upper or lower.

Every body would *appear* to revolve round the earth, each in its own "day." The *solar day* is the standard day for human beings, since our life is regulated by day and night in alternation. Unfortunately the sun's apparent day is not of constant duration, so its average value is taken and reproduced by chronometers as a *mean solar day*. The *mean sun* is a useful fiction, a pace-maker and time-keeper for all other bodies. A day of Greenwich mean time begins as the mean sun crosses the meridian of Greenwich, and is counted at the rate of four minutes for each 1° of longitude traversed westwards up to 24 hours for the complete revolution of 360°. Local mean time is reckoned from the meridian of the place or ship, so for a ship in 60° west longitude the mean sun is already four hours west of Greenwich when the local or ship day begins. Hence the rhyme, and the reason for it:

> "Longitude *West*, Greenwich time *best*:
> Longitude *East*, Greenwich time *least*."

Hence also the loss or gain of a day when circumnavigating the world. M. Jules Verne's hero journeying east was meeting the sun earlier each day, so his 80 days were 80 *short* days of G.M.T. and he had one to spare at the end, as his

bet was based on Greenwich mean time, and not on the local time of his journey which varied day by day.

In fact G.M.T. is merely a measure of the portion of the revolution completed by the mean sun from Greenwich meridian—that is to say, of the west longitude of the mean sun whose position is thus defined by the aid of the chronometer. The apparent geographical longitude of all other bodies is referred to that of the mean sun.

The actual, real, visible sun is, as already mentioned, a bad time-keeper. His "time"—*apparent solar time*—needs certain minutes and seconds to be added to it or subtracted from it to "equate" it to mean solar time. This correction is the *Equation of Time*, tabulated in the *Almanac* with the "+" (or "−") in front of it. Of course Greenwich apparent solar time "G.A.T." is the geographical longitude of the real sun whose position is thus known. For example (see p. 85):

	h	m	s
At G.M.T. Jan. 1st . . .	2	15	2
EQN. is		−3	30
So G.A.T.	$=2^h$	11^m	32^s

The equivalent in longitude is 32° 53′ W.
The declination, or latitude, is 23° 3′ S.

and the sun's apparent place is known. To deal with the stars (including moon and planets) a fixed point in the heavens is chosen and stars are referred to it. It is called the First Point of Aries, or *Aries* for short; and it does not matter in the least for present purposes where it is or why it was chosen. It suffices that it is a useful fiction, a pace-maker, a time-keeper for the stars. (See Fig. 11, p. 88.)

The reader must return to his station at the earth's centre, and standing as before hold his hand as in the sketch. The thumb is pointed to the meridian of Greenwich (*G*), the middle finger to the mean sun (*M* ☉), and the little finger to Aries (♈). This last symbol is a plausible hieroglyphic of a ram's head and horns, since *Aries* in Latin is *ram* in English.

The difference of longitude between the meridians of mean sun and Aries, measured eastwards from Aries, is the *right ascension* of the mean sun (R.-A.M.S.) It is given in the

Almanac in hours, &c., of time, but these are convertible to degrees as usual. Thus the position of Aries in longitude is known. Quite reasonably, his west longitude is called Greenwich *sidereal* time, since he is the standard or mean star. Take a case:

	h	m	s
At G.M.T. Jan. 1st . . .	6	10	15
R.-A.M.S. (see p. 85) . .	18	42	11
so G.S.T.	$=24^h$	52^m	26^s

The twenty-four hours is one revolution to spare, and may

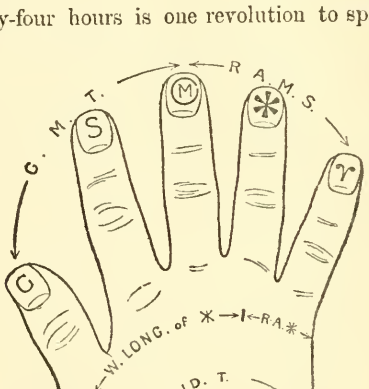


FIG. 11.

be thrown away. Anyhow, the position of *Aries* in longitude is known.

Next consider the (✳) The ring finger is pointed to the meridian of any star. The difference of longitude measured eastward from the meridian of Aries to that of the star is the star's right ascension (✳'s R.-A). So on subtracting it from Greenwich sidereal time, the remainder is the geographical longitude of the star's apparent place.

For instance take *Hamel* (α Arietis) at the time last mentioned:

	h	m	s
G.S.T. is	24	52	26
Hamel's R.-A. (see p. 85) .	2	2	20
Hamel's W. LONG.= .	22	50	6
or E. LONG.= .	1	9	54

The equivalent in longitude is 17° 28½′ E.
The declination or latitude is 23° 3½′ N.

and the star's position is known.

This sketch summarises graphically by rule of thumb all the astronomy needed to fix a ship's position. There are also just one or two elements used in correcting altitudes taken with the sextant.

It will be remembered that the sextant can measure angles. The *altitude* of a body is the angle measured vertically from the horizon to the body. If the part observed be a *limb* of the sun or moon, the semidiameter must be applied to reduce the altitude to the centre. There may be an error in the instrument; if so, it is allowed for. A correction must be made for the sloping downwards of the line of sight to the horizon (*Dip*), and also for the curving of the line of sight to the star (*Refraction*). Finally, to change to the point of view of our ideal central observer, a correction for *Parallax* is necessary. As a matter of fact it takes less time to correct an altitude than to enumerate the corrections. They are tabulated *en masse* in all up-to-date nautical tables, and need not be further mentioned.

Now consider what is the meaning of an altitude. Suppose the sun's corrected altitude to be 44° 27½′. The *vertical* is of course at right angles (90°) to the horizontal, and the vertical line is the direction of the *zenith* or point overhead. The angular distance of the sun from the zenith is therefore the defect of his altitude from 90°. This is called *zenith distance*, and in this case is 45° 32½′.

But as viewed by the central observer, this is simply the angle at the centre between the actual place of the ship and the apparent place of the sun, or the great-circle distance of the ship from the sun's geographical position.

The conclusion then is that the ship is 45° 32½′ distant from the sun's place, which, as has been shown, can be found. The information derived from "taking a sight" of the sun or a star is of precisely the same nature as that derived from measuring distance from a lighthouse.

To fix ideas, take the date of Jan. 1st. $2^h\ 15^m\ 2^s$ of G.M.T. (see p. 87) and the place of the sun as there found:

23° 3′ S., 32° 53′ W.

Then, with zenith distance 45° 32½′ draw on the globe a circle about the sun as centre, and the ship is located with certainty on that line. Also she is located by dead reckoning (see p. 83) within a circle of doubt, so that an astronomical altitude narrows the possible and probable position of the ship down to a line of limited length drawn on the globe.

But a globe would be of impossible size if it were large enough to be of use, so calculations by spherical trigonometry are made to find this line and draw it on the chart. These are exemplified in the next chapter.

Broadly speaking, the method is to assume a dead-reckoning point (*A* on chart, p. 92) and to compute its great-circle distance from the sun. The difference between this distance and the ship's distance from the sun is the amount the assumed point *A* has to be shifted towards or away from the sun to arrive at a *possible* position—*Z* on the chart. Then the limited line through *Z*, perpendicular to the sun's direction and bounded by the circle of doubt, is both possible and probable. and is called a line of position or "*Position Line.*"

CHAPTER IX

The Day's Work

Without further preface, and with but small explanation in passing, a series of imaginary observations dated the 1st January 1914 will now be worked. They exemplify the ordinary "day's work" of navigation.

(1) *At noon of 1st January S.S.* Blank *was in* 38° 25′ *S.*,

18° 21′ *E. Required Mercator course and distance to her destination, St. Helena, in* 15° 55′ *S.*, 5° 44′ *W.*

Position . .	38° 25′ S.	mer 2500	18° 21′ E.
St. Helena .	15° 55′ S.	mer 968	5° 44′ W.
diff. .	22° 30′	1532	24° 5′
	1350′		1445′

1445	log 3.1599	1350′	log	3.1303
1532	log 3.1853	43°20′	L. sec	0.1382
43°20′	L. tan 9.9746	1856	log	3.2685

The course is therefore N. 43° W., and distance to St Helena 1856 miles.

(2) *Ship then steamed at* 12 *knots on this course for* $3^h\ 24^m$, *when sights were taken. Required her dead-reckoning position:*

Distance run is $12 \times 3.4 = 41$ miles.

$$41' \text{ on C° N. } 43° \text{ W.} \equiv \begin{cases} 30' \text{ N. diff. LAT.} \\ 28' \text{ W. DEP.} \end{cases}$$

and this DEP. corresponds to 36′ W. diff. LONG.

Applying these differences to LAT. and LONG. at noon:

$$\text{Position } \begin{cases} 37° \ 55' \text{ S.} \\ 17° \ 45' \text{ E.} \end{cases} \Big\} \text{estimated.}$$
$$3^h\ 24^m \text{ P.M.}$$

This is shown with a circle of doubt at *A* on the chart.

(3) *Sights of the sun were now taken in this estimated position at G.M.T. Jan.* $1^d\ 2^h\ 5^m\ 2^s$. *The sun's zenith distance was* 45° 32½′.

At this moment of G.M.T. in the last chapter we found the sun's geographical position to be 23° 3′ S., 32° 53′ W. We calculate the great-circle distance from this point to *A* in 37° 55′ S., 17° 45′ E.

A	17° 45′ E.		
☉	32° 53′ W.		
diff.	50° 38′	L. ver . . .	9.5631
A	37° 55′ S.	L. cos . . .	9.8970
☉	23° 3′ S.	L. cos . . .	9.9639
		L. ver . . .	9.4240
		N. ver . . .	.2055
diff.	14° 52′	N. ver . . .	.0355
dist.	45° 29½′	N. ver . . .	.2990

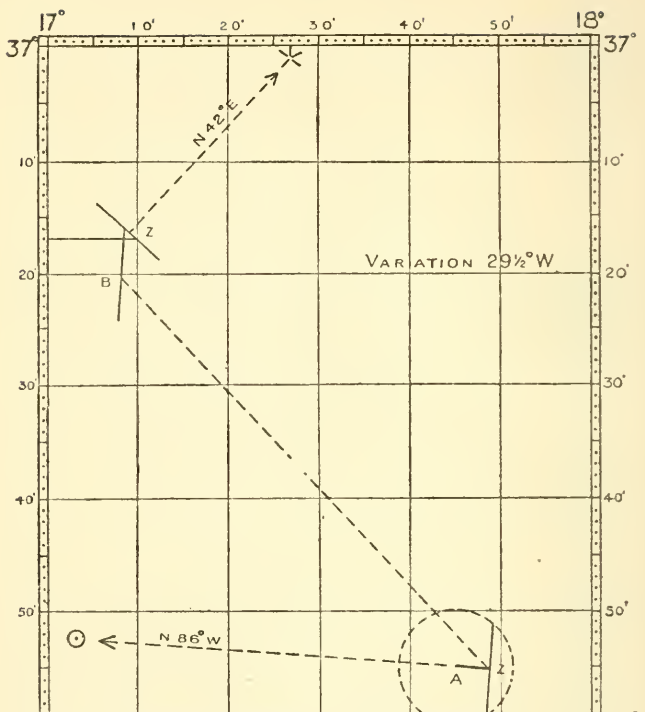


FIG. 12.

The direction or bearing of the sun might be computed, but there are tables which give it by inspection. It is N 86° W.

Now A is distant 45° 29½′ from ⊙
but ship „ „ 45° 32½′ „ „
∴ A must be shifted 3′ away from ⊙.

This is done on the chart at Z. Through Z is the position line.

(4) *From Z in* 37° 55′ *S.*, 17° 49′ *E., steamed on same course and speed until G.M.T. Jan.* 1ᵈ 6ʰ 10ᵐ 15ˢ, *when sights of stars were taken. Required the estimated position.*

The distance run is $(3.9 \times 12 =)$ 47 miles, and is drawn on the chart, arriving at B in 37° 20½′ S., 17° 8½′ E. The position line is transferred to this point, and (if the run is correct) the ship lies somewhere on its length.

(5) *At the time above mentioned, the zenith distance of Hamel was 60° 20½′, the star being nearly due north.*

On p. 89 the geographical position of *Hamel* at this moment was found to be:

23° 3½′ N., 17° 28½′ E.,

so that the star is practically on the ship's meridian. The zenith distance is therefore interpreted as the distance of the ship *due south from the star*, whence:

Hamel is in	23° 3½′ N.
Ship is	60° 20½′ S. of star
Ship is in	37° 17′ S.

A short length of this parallel is drawn on the chart, and cuts the first-position line (as transferred to B) in the point Z:

37° 17′ S., 17° 9′ E.

This is therefore the ship's position, a Fix by two astronomical observations, subject only to errors in run. A third sight checks these.

(6) *At G.M.T. Jan. 1d 6h 10m 16s, another observer took an altitude of Aldebaran and found the zenith distance to be 64° 11′.*

For this date, as on p. 89, we find the geographical position of *Aldebaran* to be

16° 20½′ N., 54° 38½′ E.

and now we compute his distance from the point where the ship was fixed:

Z	17° 9′ E.	
*	54° 38½′ E.	
diff.	37° 29½′	L. ver 9.3150
Z	37° 17′ S.	L. cos 9.9007
*	16° 20½′ N.	L. cos 9.9821
		L. ver 9.1978
		N. ver .1577
diff.	53° 37½′	N. ver .4069
dist.	64° 11½	N. ver .5646

The bearing of the star is N. 42° E., so the result seems to imply that Z ought to be shifted $\frac{1}{2}'$ nearer to the star. But really it confirms the previous sights. The new position line is shown on the chart, and the ship lies within the very small "cocked hat" formed by the three lines.

Such a result would be eminently satisfactory in practice.

A last example will illustrate how the compass is checked to see whether its errors are properly compensated. This is done by comparing the bearing calculated for the sun or other body with the bearing observed by compass, after making allowance for the variation noted on the chart.

At the observation of the sun worked above, in (3), *the compass bearing was N. 56° W. Required the deviation of the compass, if any.*

Using the data of (3), we calculate the true bearing:

37° 55′	L. sec . . . 0.103
44° 30′	L. sec . . . 0.147
6° 35′	
66° 57′	
60° 22′	½ L. ver . . . 4.852
73° 32′	½ L. ver . . . 4.928
94° 6′	L. ver . . . 0.030

This angle is measured from the south pole and is S. 94.1° W., or N. 85.9° W.

True Bearing of Sun . .	N. 85.9° W.
Allow Variation from chart .	29.5° W.
Magnetic Bearing, . . .	N. 56.4° W.
Compass Bearing, . . .	N. 56.0° W.
Deviation of Compass . . .	0.4° W.

Which is the error for the course steered, namely, N. 43° W. *true*, or N. 13½° W. *magnetic*. If the half-degree of error were thought reliable, the compass course would be made N. 13° W.

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THIS is perhaps the place most proper for the statement that the writer, having completed his task, is fully aware that he has added nothing to the knowledge common to all seamen. In pursuing the fundamental facts of astronomical and mathematical navigation, however, he has purposely abandoned beaten tracks, and taken a short cut which may be found convenient though unfamiliar. The general reader will, it is hoped, have found some store of novel fact and phrase explained without undue pedantry of technicalities. If he wishes to follow the subject further in more professional works, he cannot do better than apply to Mr. J. D. Potter, Admiralty agent, 145 Minories, E.C. For seamanship, there are the small *Handbook* and the two volumes of the *Manual*, both excellent Admiralty publications, very cheap and reliable.

For machines, &c., and pilotage, the small volumes of Lord Kelvin's *Lectures* (Macmillan) should certainly be read. The introduction to any volume of the *Sailing Directions* is of the first importance as defining the strictest nautical practice. For tides nothing is better than Sir George Darwin's *Tides and Kindred Phenomena*.

Of actual text-books of nautical astronomy and astronomical navigation there is no lack, yet none of them can be recommended without reserve. This reservation applies to the writer's *Modern Navigation*, the first edition of which is too difficult and the second too elementary. It is, nevertheless, standard for the Royal Navy. Previous text-books were those of Martin and Stebbing. The mercantile marine use the treatises of Raper, Norie, and Rosser. Of these the first is without doubt the best bit of work yet done in navigation. Raper was a practical seaman, a good mathematician, and a lucid writer. Unfortunately his day was that of sails and not of steam, and his work is somewhat out of date.

The most popular of recent books is Lecky's *Wrinkles*. Captain Lecky discourses with vigour and originality on things of the sea and things in general at great length. His first-hand information is most useful and his style entertaining, but he does not pretend to any exact mathematical exposition. The book should be read.

Collections of nautical tables are numerous. The Royal Navy uses the writer's edition of *Inman's Tables*. These, as reconstructed in 1906, are well adapted to modern requirements. *Raper's Tables* (a twentieth edition, with *Appendix* by the writer, is now in the Press) are most used in the merchant service. Those of *Norie* and *Rosser* have a good circulation.

This list of books may serve for guidance.

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